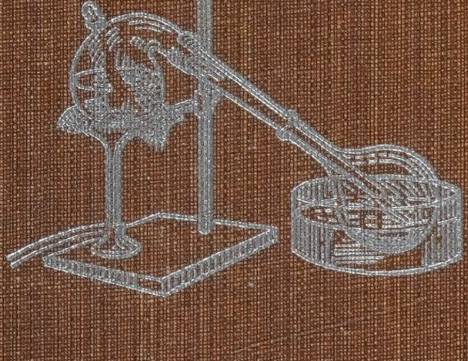
SIXTH EDITION

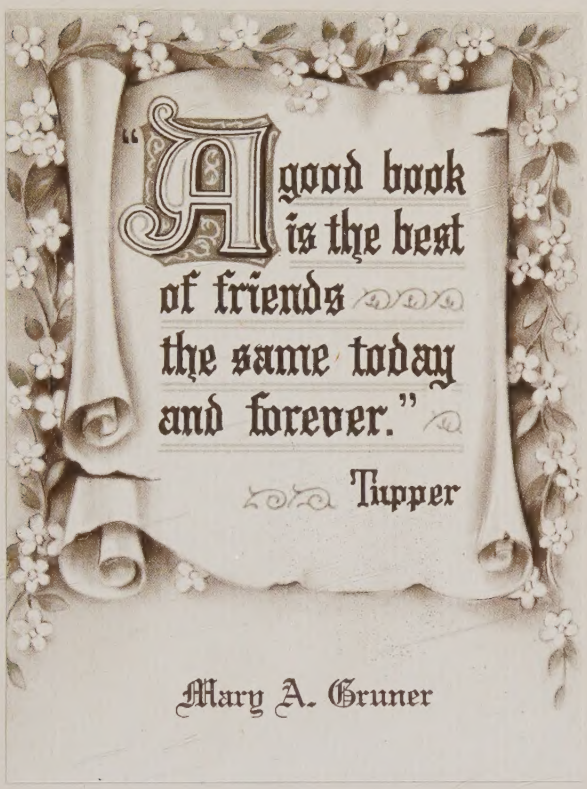
PRINCIPLES OF CHEMISTRY



ROE

TABLE OF ELEMENTS, SHOWING THEIR SYMBOLS, ATOMIC NUMBERS, AND ATOMIC WEIGHTS

	SYMBOL	AT. NO.	AT. WEIGHT		SYMBOL	AT. NO.	AT. WEIGHT
Actinium	Ac	89	227.00	Mercury	Hg	80	200.61
Alabamine	Ab	85	221.00	Molybdenum	Mo	42	96.00
Aluminum	Al	13	26.97	Neodymium	Nd	60	144.27
Antimony	Sb	51	121.76	Neon	Ne	10	20.183
Argon	A	18	39.944	Nickel	Ni	28	58.69
Arsenic	As	33	74.93	Nitrogen	N	7	14.008
Barium	Ba	56	137.36	Osmium	Os	76	190.80
Beryllium	Be	4	9.02	Oxygen	O	8	16.00
Bismuth	Bi	83	209.00	Palladium	Pd	46	106.70
Boron	B	5	10.82	Phosphorus	P	15	31.02
Bromine	Br	35	79.916	Platinum	Pt	78	195.23
Cadmium	Cd	48	112.41	Polonium	Po	84	210.00
Calcium	Ca	20	40.08	Potassium	K	19	39.10
Carbon	C	6	12.00	Praseodymium	Pr	59	140.92
Cerium	Ce	58	140.13	Protoactinium	Pa	91	
Cesium	Cs	55	132.81	Radium	Ra	88	225.97
Chlorine	Cl	17	35.457	Radon	Rn	86	222.00
Chromium	Cr	24	52.01	Rhenium	Re	75	186.31
Cobalt	Co	27	58.94	Rhodium	Rh	45	102.91
Columbium	Cb	41	93.30	Rubidium	Rb	37	85.44
Copper	Cu	29	63.57	Ruthenium	Ru	44	101.70
Dysprosium	Dy	66	162.46	Samarium	Sm	62	150.43
Erbium	Er	68	167.64	Scandium	Sc	21	45.10
Europium	Eu	63	152.00	Selenium	Se	34	79.20
Fluorine	F	9	19.00	Silicon	Si	14	28.06
Gadolinium	Gd	64	157.30	Silver	Ag	47	107.88
Gallium	Ga	31	69.72	Sodium	Na	11	22.997
Germanium	Ge	32	72.60	Strontium	Sr	38	87.63
Gold	Au	79	197.20	Sulfur	S	16	32.06
Hafnium	Hf	72	178.60	Tantalum	Ta	73	181.40
Helium	He	2	4.002	Tellurium	Te	52	127.50
Holmium	Ho	67	163.50	Terbium	Tb	65	159.20
Hydrogen	H	1	1.0078	Thallium	Tl	81	204.39
Illinium	Il	61	146.00	Thorium	Th	90	232.12
Indium	In	49	114.80	Thulium	Tm	69	169.40
Iodine	I	53	126.932	Tin	Sn	50	118.70
Iridium	Ir	77	193.10	Titanium	Ti	22	47.90
Iron	Fe	26	55.84	Tungsten	W	74	184.00
Krypton	Kr	36	82.90	Uranium	U	92	238.14
Lanthanum	La	57	138.90	Vanadium	V	23	50.95
Lead	Pb	82	207.22	Virginium	Vi	87	224.00
Lithium	Li	3	6.94	Xenon	Xe	54	131.30
Lutecium	Lu	71	175.00	Ytterbium	Yb	70	173.50
Magnesium	Mg	12	24.32	Yttrium	Y	39	88.92
Manganese	Mn	25	54.93	Zinc	Zn	30	65.38
Masurium	Ma	43		Zirconium	Zr	40	91.22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Tupper
Mary A. Gruner

PRINCIPLES OF CHEMISTRY

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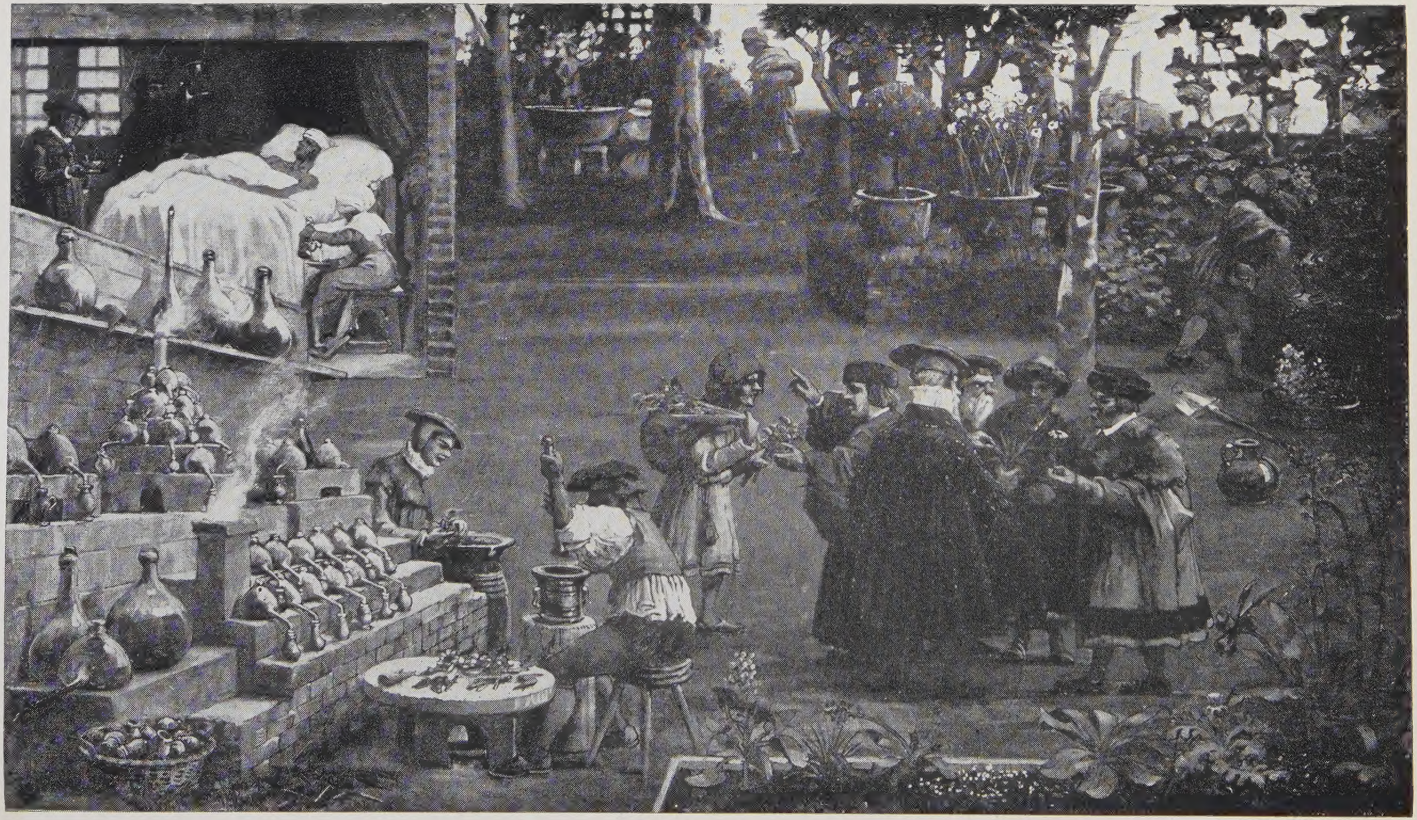

PLATE I.—THE ALCHEMICAL MAKING OF MEDICINE IN THE SIXTEENTH CENTURY.
From a painting by Michael Diemer. (Courtesy of the Fisher Scientific Co.)

PRINCIPLES OF CHEMISTRY

An Introductory Textbook of Inorganic, Organic, and Physiological Chemistry for Nurses and Students of Home Economics and Applied Chemistry

BY

JOSEPH H. ROE, Ph.D.

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SIXTH EDITION

ST. LOUIS
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1944

THIS COMPLETE EDITION IS PRODUCED IN FULL COMPLIANCE WITH THE GOVERNMENT'S REGULATIONS FOR CONSERVING PAPER AND OTHER ESSENTIAL MATERIALS.

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TO
MY MOTHER

PREFACE TO THE SIXTH EDITION

A sixth edition of this book has been prepared in order to bring the subject matter up to date and to introduce certain modifications in the method of treatment.

In this edition the material is presented in units of related subject matter arranged in a progressive order. It is believed that this unit plan of presentation is an effective approach to the subject of chemistry for nurses. We have been privileged to receive criticisms and suggestions from outstanding teachers and workers in the field of nursing education and their advice has been incorporated into this edition. Some new material has been added, but deletions were necessary; hence the present edition is of approximately the same size as the last edition.

The new subject matter introduced includes discussions and laboratory exercises upon standard solutions, titrations, indicators and buffers. Also, in this edition, enzymes and digestion have received a much more extensive treatment; a new chapter on respiration has been introduced; a fuller discussion of the subject of excretion has been made; and interpretations of new discoveries in the chemistry of vitamins and hormones have been presented.

The chapter on nutrition in former editions has been withdrawn. It seems that in a book of this kind nutrition in its broadest sense need not receive special treatment. The metabolism of nutrients, however, is basically a chemical subject and should be taught from the chemical point of view. We have, therefore, developed a unit on metabolism which is a much more extensive treatment of this phase of subject matter than that offered in former editions. This unit includes a discussion of the metabolism of practically all of the constituents of the diet, except the vitamins which are treated in a separate unit.

In response to requests for material upon units of measurement we have placed in the appendix a condensed treatment of such subject matter.

In this edition the laboratory guide has been separated from the didactic discussion and placed in a separate cover in loose-leaf form. This enables the instructor to have sheets removed from the laboratory manual for examination and thus permits the correction and return of laboratory exercises at desired times without collection of the books. This change was made in response to many requests from teachers.

Five new exercises have been added to the laboratory guide. These are: visualizing the structure of the atom; oxidation and reduction; indicators and standard solutions; energy; vitamin C or ascorbic acid.

The amount of material presented in this text makes it adaptable to courses in chemistry for nurses ranging from 45 to 90 hours. There is more material than can be covered in 45 hours, but this allows the instructor considerable freedom in choice of subject matter. For courses of 60 to 90 hours it is believed there is ample material, though less choice of subject matter can be made in the longer courses.

In preparing this edition the author received much valuable aid. It is a pleasure to acknowledge the very helpful criticisms and advice of the following teachers: Miss Nita E. Greene, Instructor in Social Sciences, The Capital City School of Nursing, Gallinger Municipal Hospital, Washington, D. C.; Dr. Theresa I. Lynch, Director of Nursing, Hospital of the University of Pennsylvania; Dr. David E. Mudge, The Martinsburg High School, Martinsburg, W. Va.; Dr. Henderika J. Rynbergen, Assistant Professor of Sciences, Cornell University—New York Hospital School of Nursing; Dr. Laurence G. Wesson, Biochemist, the Forsyth Dental Infirmary. We express appreciation also to Dr. Estelle E. Hawley and Miss Grace Carden for the use of illustrations from their book, *The Art and Science of Nutrition.*

JOSEPH H. ROE

Washington, D. C.

PREFACE TO THE FIFTH EDITION

A fifth edition of this book has become necessary to enable the author to bring the subject matter up to date and to introduce new features in response to suggestions of teachers and reviewers.

In preparing the different editions of this book, the author has followed a definite plan. The first major objective was to present the fundamental principles of inorganic chemistry. The second broad objective was a presentation of selected phases of organic chemistry. The section on organic chemistry of necessity had to be brief and has been confined to a discussion of representative classes of organic compounds, the purpose of this section being to give the student a background for the subsequent treatment of physiological chemistry. The third objective of this book was to present selected facts and principles of physiological and clinical chemistry. The chemical nature of carbohydrates, proteins and fats; digestion; metabolism; nutrition; the physiological effects of vitamins and hormones; the excretion of waste products; and the chemical basis of diseased conditions have received detailed treatment. The fourth outstanding objective was to offer a series of laboratory experiments designed to supplement the theoretical work presented and to give the student training in laboratory techniques. The original plan of the book has been followed in this new edition.

Throughout this work efforts have been made to stress the significance of chemistry in the interpretation of normal living processes, in the development of an understanding of diseased conditions, and in the creation of a rational basis for therapeutic procedures. The practical applications of chemistry to the problems of nursing have received special emphasis. The rather full discussion of physiological chemistry and nutrition also makes this textbook adaptable to instruction in courses in dietetics, nutrition, and other courses involving applied chemistry. The fundamental interpreta-

tions of chemistry and the emphasis placed on the relation of chemistry to life also make this book useful for imparting culture.

In the preparation of this edition every phase of the course in chemistry for nurses in the Curriculum Guide for Schools of Nursing, issued by the National League of Nursing Education in 1937, has been covered. The suggestions of this guide represent minimum requirements, however, and the author feels well justified in offering additional material since the needs and objectives of teachers and schools of nursing are variable. In the selection of material for this text, the author has been guided by his own experience as a teacher of medical students and nurses and by the many helpful suggestions of teachers of nurses' courses in chemistry and reviewers of previous editions. The book in its present form contains adequate material for the more comprehensive courses in chemistry for nurses. It is also adaptable to short courses because it follows the unit plan, being divided into 34 chapters and 35 laboratory experiments. Thus a satisfactory degree of flexibility in the choice of subject matter is offered to teachers of shorter courses.

Considerable revision has been made in this edition. Recent discoveries concerning the nucleus of the atom have necessitated a new interpretation of the structure of matter. These findings, like all of the discoveries of science, have not broken down fundamental ideas, but, on the contrary, have added to and improved previous conceptions. Thus the inclusion of the neutron in the nucleus of the atom has made simpler and clearer the interpretation of the structure and behavior of matter. An elementary discussion of hydrogen-ion concentration and pH, buffers, water balance, and natural and artificial radioactivity has also been introduced.

The amount of organic chemistry that should be presented in a nurses' course in chemistry is a distinct problem. In past editions, the position has been taken that the minimum essentials necessary to give the student a background for physiological chemistry should be offered. How-

ever, the author has received suggestions from teachers that his presentation of organic chemistry was somewhat brief. In response to this criticism, some additional material upon organic chemistry has been introduced in this edition.

For this edition there has been prepared a complete set of instructions and questions to serve as a guide to students in recording the results of laboratory experiments. This material will enable the student to be more systematic in classifying and recording observations upon experiments, and hence will considerably improve the laboratory instruction.

Seventeen new illustrations have been introduced in this edition, in addition to a redrawing of all the older charts on the structure of the atom.

The author has endeavored not to overwrite any phase of the subject and to keep this edition near the size of the last two editions. The accomplishment of this purpose has necessitated the deletion of some material. The chapter on units of measurement has been withdrawn and other less relevant material has been deleted. The amount of subject matter in this edition is approximately the same as that of the last edition. The additional pages are almost completely accounted for by the space taken by the new illustrations.

The author takes pleasure in acknowledging the aid received in the preparation of this edition. Special thanks are due to Miss Mannevillette Sullivan for the preparation of the new figures on the structure of the atom and several other new illustrations. The author also expresses grateful appreciation to the following for permission to reproduce illustrations as indicated: To the Fisher Scientific Company, for the frontispiece; to the American Hospital Supply Company, for Fig. 9; to the University of Illinois College of Agriculture, for Fig. 23; to the editors of the *National Geographic Magazine,* for Fig. 25 and color plate II; to P. Blakiston's Son and Company, for Figs. 29 and 39; to the Cambridge University Press and the Macmillan Company, for Figs. 35 and 38; to Longmans, Green and Company, for Fig. 36; to the Macmillan Company, for Fig. 37; to Dr. Paul L. Day and the editors of the *Journal of Nutrition,* for Fig.

40; to the Yale University Press, for Fig. 41; to Dr. W. C. Rose and the editors of the *Journal of Biological Chemistry,* for Fig. 42; and to Parke, Davis and Company, for color plate III.

The author desires to acknowledge the aid of Dr. Sidney Thayer, Assistant Professor of Biochemistry, St. Louis University School of Medicine; Dr. L. Earle Arnow, Instructor in Physiology, University of Minnesota Medical School; Dr. Ralph E. Gibson, Physical Chemist, Geophysical Laboratory, Carnegie Institute of Washington and Adjunct Professor of Chemistry, George Washington University. These colleagues gave valuable assistance as critics of former editions.

JOSEPH H. ROE.

Washington, D. C.

PREFACE TO THE FIRST EDITION

This book has been written to meet the requirements of the forty-five- to sixty-hour courses in chemistry for nurses recently recommended by the National League of Nursing Education. In general, the outline published by a committee of the latter organization has been followed, but certain minor deviations in the treatment of the organic section have seemed advisable.

Special efforts have been made to use language as simple and popular as is consistent with scientific writing and to prepare the way for the presentation of each topic. The theoretical principles, which can be successfully presented in the time allotted, have been discussed in detail. Such phases of chemistry as the structure of the atom, the kinetic theory of gases, the composition of body tissues and excretions, etc., the author believes would be confusing in a course of this kind, and hence material of this nature has not been introduced. The applications of chemistry to biology, medicine, and the arts, have received special emphasis.

The author is conscious of the great difficulty of teaching the structural side of organic chemistry in a course of this kind, and accordingly has introduced no more organic

chemistry than is necessary to give a general idea of the carbon compounds, and of the nature of proteins, carbohydrates, and fats. On the other hand, the author believes that the physiological aspects of chemistry, such as digestion and metabolism, can be successfully taught and should be stressed in a nurses' course, and has, therefore, introduced considerable material along the lines of physiological chemistry.

Inasmuch as the discussions involving physiological chemistry have received such a full treatment, the author believes that this work will be adaptable to elementary courses in schools of home economics and to other courses involving applied chemistry.

A comprehensive set of laboratory experiments designed to supplement the theoretical work presented and to give the student training in laboratory technique is included in the latter part of the book. The experiments selected do not require complicated apparatus, and the technique has been so adapted that the students can obtain impressive results.

It is a pleasure to acknowledge the assistance of colleagues and friends in this work. The inorganic section of the manuscript was read by Dr. Charles E. Munroe, of the National Research Council, and by Dr. Frank A. Hornaday, of the George Washington University Medical School; the organic and physiological section was reviewed by Dr. Eugene R. Whitmore, of the Georgetown University Medical School. The manuscript was greatly improved by the suggestions of these reviewers. The illustrations were prepared by Prof. Oliver J. Irish, of the George Washington University Medical School, who also made valuable suggestions concerning the preparation of the work. The author also acknowledges the courtesy of the Bureau of Investigation of the American Medical Association in supplying an interesting chart concerning vitamins.

JOSEPH H. ROE.

Washington, D. C.

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PRINCIPLES OF CHEMISTRY

UNIT I

ORIENTATION

CHAPTER I

THE SCOPE AND BACKGROUND OF CHEMISTRY

Matter and Energy.—*Matter is anything that occupies space.* It includes any of the substances which we can see, feel, or perceive by the senses. Plants, animals, air, water, rocks, soil, metals, in short, the substances composing the earth, the moon, the sun, and the stars, are what is meant by the word matter. *Energy is the ability to do work, or the capacity to put matter in motion.* There are different forms in which energy is manifested, such as heat, light, electricity, motion, chemical energy.

Science.—For thousands of years man has made observations of the things about him and passed on to succeeding generations his thoughts regarding them. Man's early ideas concerning the universe and the substances of which it is composed were naturally very simple and crude. These early ideas appeared first as myths, which were often interwoven with religion, later as theories proposed by the philosophers, all of which were imaginative and have literary charm to the present-day reader, but were lacking in exactness because they were not based upon man's greatest test of truth, namely, experimentation. As time passed, the earlier observations were found by experience to be inexact, and the old conceptions gradually gave way to new ones which contained more of the truth because they were submitted in a greater degree to the tests of experimentation. Thus a mass of ideas about matter and the universe has gradually accumulated, and has been recorded in a system-

atic form. This accumulation of knowledge of the universe constitutes the physical sciences. *A science is the systematic arrangement of observations and the conclusions derived from them.* The sciences of today contain much that is true because in them are observations that have been made thousands of times by thousands of different observers. When an occurrence happens many times in the same manner, the observation of this similarity of result becomes a fact which the observer can feel very sure is true. Out of such often repeated observations have developed the principles or laws which are the basis of the sciences. In science, *a law is a statement of a fact which has been demonstrated to be true by often repeated tests, or experiments,* and which we believe would be verified at any future time we choose to repeat these tests.

Chemistry Defined.—*Chemistry is a science which deals with the nature of matter and the changes which matter undergoes.* Its purpose is to find out what are the simplest parts of matter; how these parts can be separated in a pure form from crude matter, or put together, or rearranged, to produce new forms of matter; and the energy that is liberated, or absorbed, in making these rearrangements of matter. The energy changes of matter are considered more especially, however, by the science called *physics.* Physics and chemistry, of necessity, overlap in their treatment of material, because both have for their purpose the investigation of matter.

History of Chemistry.—The earliest recorded investigators in the field of chemistry were known as *alchemists,* and the principles which they developed and followed were called *alchemy.* The great purpose of the alchemists was to convert base metals, like lead, into gold. In seeking a method to accomplish this dream they produced little of value to the world, but as pioneer experimenters with matter they initiated the science of chemistry, and in this respect they made an important contribution to civilization. The earliest records of alchemy date back to the beginning of the Christian Era. It probably originated with the Alexandrian

Greeks, and later spread to Egypt, Rome, and the nations of Western Europe. Its decline and gradual disappearance began in the sixteenth century with the advent of the *iatrochemists,* or *physician chemists.*

The iatrochemists represent a distinct change in the purposes of chemistry. They held that the function of chemistry is to make medicines, and not to transmute base metals into gold. The most illustrious member of this school was Paracelsus, who advocated the doctrine that man is made of chemical substances (mercury, sulfur, and salt). When he is healthy, these chemical materials are present in his body in correct proportions; but when he is sick, some of these chemical substances are not present in sufficient amounts. Therefore, to cure the patient, it is necessary to dose him with those substances which are lacking in his body. In these days of chemistry and medicine it is apparent that there was logic in the methods of Paracelsus and some truth in his ideas. In passing it should be said that the doctrines of Paracelsus and the iatrochemists exerted a very favorable influence upon the development of both medicine and chemistry by turning chemical investigations into more desirable and more productive channels.

Just when the modern age of chemistry began is somewhat indefinite, but we can conservatively say that practically all the chemistry we know at the present time is a development of the past one hundred and fifty years.

Divisions of Chemistry.—Chemistry is divided into two major branches: inorganic and organic. Inorganic chemistry deals more especially with inanimate or lifeless matter; it includes a study of all the elementary substances except carbon. Organic chemistry considers matter of which living things are composed or which is closely associated with living things; it is essentially a study of the compounds of carbon. Both of these great divisions have many subdivisions, such as analytical, synthetical, physical, physiological, and so on. The division of chemistry into inorganic and organic is not a clear-cut separation and is to be regarded as a convenience for purposes of study.

Three States of Matter.—There are three states, or phases, in which matter exists: the solid, the liquid, and the gas. *Matter in the solid state has definite shape; in the liquid state it must take the shape of the container in which it is placed; and in the gaseous state it has no definite shape, the individual particles being free to move about in space.* Wood is a solid; it has definite shape, because the particles of which it is composed are held together very closely and firmly. Water at room temperature is a liquid; the individual particles composing water at this temperature are not packed together as closely as in a solid, hence water is free to move and take the shape of the vessel in which it is placed. Air is matter in the gaseous state. The individual particles of air are a great deal farther apart than the particles of water or wood; and, having much greater freedom of motion, air particles tend to stay apart, and will not form a mass with definite shape like a liquid or a solid.

Whether matter is in the solid, the liquid, or the gaseous state is determined by its temperature and the pressure under which it exists. Thus at atmospheric pressure and at temperatures below 0° Centigrade, water is a solid; above 0° it is a liquid; and when heated to 100° Centigrade it becomes a gas. For a given pressure the temperature at which a solid passes into the liquid state is called its *melting point;* the temperature at which a liquid passes into the gaseous state is called the *boiling point* of the substance. The boiling point of a liquid is the temperature at which the pressure of the vapor leaving the surface of the liquid becomes equal to the pressure of the atmosphere above it. The melting points and boiling points recorded in textbooks apply at a pressure of one atmosphere unless otherwise stated. Passing from the solid to the liquid state is called *liquefaction;* passing from the liquid state to the gaseous or vapor state is called vaporization or *evaporation.*

Properties of Matter.—One of the objectives of the study of chemistry is to reveal the nature of matter. This is done by carefully arranging all the outstanding qualities or characteristics of any substance under the heading of "prop-

erties." *A property of matter is any quality or characteristic that gives information concerning it.* Thus color, odor, taste, weight, state or phase, and how it behaves when heated or cooled, or mixed with other matter, all are characteristics which enable one to recognize the nature of a substance that is being studied. We will soon proceed to discuss the properties of substances, and it will be important for the student to memorize the outstanding properties mentioned.

Physical and Chemical Changes.—The changes which take place in matter are of two distinct kinds; they are either physical or chemical. *A chemical change is one in which a new substance is formed.* In a chemical change the substances involved lose their identity and change into other substances which have different properties. *A physical change is one in which a new substance is not formed, and the substance at the end of the change has the same properties as at the beginning of the process.* A physical change may be temporary; the properties of the substance may be altered slightly, but only temporarily, and when the treatment is completed, the substance regains its original properties. For example, if we tear a piece of paper into small bits, we are carrying out a physical change; we still have paper at the end of the process, though in a finer state of division. If we set fire to paper, a chemical change takes place; new substances, namely, ashes and certain gaseous products of burning, are formed. In burning, the paper loses its identity and new substances with different properties are formed. We may heat a platinum wire in a flame until it becomes "red hot," but as soon as it is removed, it cools, and we have unchanged platinum. The latter is a physical change. Now if we treat the platinum wire with an appropriate mixture of acids, it will dissolve, and a new substance will be formed. This change would be a chemical change.

In nature matter is constantly undergoing both physical and chemical changes. The evaporation, condensation, and freezing of water; the erosion of the land by the waters of small streams and rivers; the crumbling of rocks from the wear of rainfall and the freezing and thawing of water in

their pores; these are examples of physical changes constantly taking place in nature. An interesting example of chemical changes in nature is the formation of stalactites and stalagmites in limestone caverns. The many changes taking place in plants and animals are even more interesting examples of chemical changes in nature. There are thousands of chemical changes taking place in the human body at any instant of time. These changes are involved in the processes of the digestion and absorption of foods; the building-up of tissues; the burning of foods in the body; wear and destruction of tissues; respiration; and the elimination of waste products. Many similar chemical changes are constantly taking place in plants and in the production of foods, which are stored in the seeds, roots, and fruits of the plant.

A chemical change will later be referred to as a chemical reaction. In chemistry the words "change" and "reaction" are used as synonyms, meaning essentially the same thing.

Laws of Conservation of Mass and Energy.—When beginning the study of chemistry, the student may at first get the impression that matter is being destroyed. Thus when we pour acid over a lump of marble, the latter disappears, and it may seem, because the marble has disappeared from view, that some matter has been destroyed. But this is not true. What happens when the marble disappears is that its particles are separated and rearranged to form new substances, some of which are gaseous, some of which are in solution, and none of which is visible. If all the new substances formed are collected and weighed, the total weight will be exactly equal to the weight of the original substances before they were mixed.

Let us refer to the diagram in Fig. 1. Suppose we place in a flask a lump of marble and a test tube of hydrochloric acid and close the flask with a tight seal so nothing can escape. This is represented by Position A. The flask and contents are then weighed, and let us assume, for convenience, they weigh one pound. Now the flask is tilted until the test tube of acid is spilled upon the marble as shown in Position B. The marble will be attacked by the acid, bub-

bles of gas will be given off, and the marble will disappear. But has any matter been destroyed? We determine this by weighing the flask again. A second weighing will show the flask (Position C) and contents weigh one pound, the same weight as before the chemical change took place. (This experiment is intended to be illustrative only. It would be safe in the hands of an expert who would make sure the flask is strong enough to avoid an explosion but it would be unsafe in the hands of an inexperienced student and should not be attempted by the latter.)

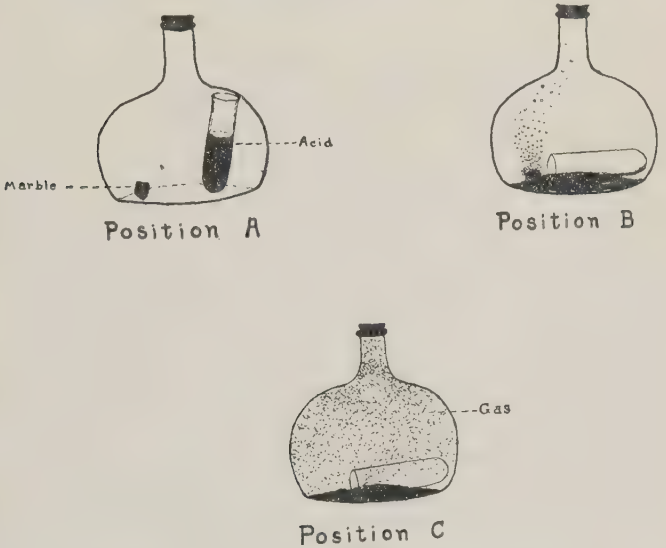


Fig. 1.—Experiment demonstrating law of conservation of mass.

The above experiment illustrates the law of the conservation of mass, which is that *in a chemical reaction the total weight of the reacting substances is equal to the total weight of the products formed.* In a chemical reaction in which there is a decomposition of matter with the formation of a gas, the matter is only broken up into smaller particles which may disappear from sight, but are not destroyed; they are merely so widely separated from each other that they are not perceptible to the senses.

Another law of importance in this connection is the *law of conservation of energy, which states that energy is never lost.* The energy used in doing work is not lost, but is transformed into other forms. The mechanical energy of running water may be transformed into electrical energy by the devices of the modern electric power plant, and the electrical energy may be used for running a street car, lighting a city, or producing heat by means of an electrical stove. The original energy of the falling water is successively transformed into several different forms of energy, which are finally dissipated and made nonutilizable after doing work, but are not destroyed.

Importance of Chemistry.—Before the advent of chemistry, knowledge of the universe was clouded with mystery and superstition, and the human race lacked most of its present-day comforts. Chemistry has fulfilled a great mission in solving many of the mysteries of nature and revealing the wonderful properties of matter. Perhaps no other subject has contributed so much to the development of human knowledge, and certainly no other science has contributed so much to human happiness by utilizing the products and forces of nature and creating new products for human use. The influence of chemistry in the production of articles for human comfort and happiness can be seen readily by noting the articles surrounding us, wherever we may be. It is practically impossible in modern times to observe an article of commerce that has not been created, improved, or influenced in some manner by an application of the principles of chemistry. It will be an interesting and instructive exercise for the student to try to note an exception to the latter statement.

Questions for Study

1. Define matter. Give ten examples of matter.
2. Define energy. In what different forms is energy manifested?
3. What is a science? What is man's most valuable method of demonstrating the truth in science?
4. What is a law in science? How were the laws of science established?

5. Define chemistry. What is the purpose of chemistry?

6. What was the purpose of the alchemists? The iatrochemists?

7. Give the two major divisions of chemistry. What is meant by inorganic chemistry? By organic chemistry?

8. Name the three states of matter. Illustrate each state by an example.

9. Define: liquefaction, evaporation, melting point, boiling point.

10. What is meant by the properties of matter? Name six properties.

11. Distinguish between physical and chemical changes. Give several examples of physical and chemical changes in nature.

12. Explain the law of the conservation of mass.

13. What is the law of the conservation of energy? Illustrate.

14. Discuss the importance of chemistry.

UNIT II

FUNDAMENTAL CONCEPTS

CHAPTER II

BASIC CONCEPTS AND DEFINITIONS

Elements.—The early philosophers of Greece, Egypt, and other nations of antiquity believed that there were four primary substances, earth, water, air, and fire, which compose all the forms of matter in the universe. Of these four substances, the earth was typical of solids; water stood for liquids; air for the winds and the breath; and fire was a mystic essence which existed in greater or less amounts in all things capable of burning. This four-element concept of matter was the basis of all attempts to classify the many forms of matter in the world up to about two hundred years ago. It finally disappeared when investigators found that simpler substances could be made from earth, water, or air, and that fire is a manifestation of matter at a high temperature.

It is now known that matter is composed of 92 primary substances called elements. (See the table of the elements on the inside page of the front cover of this book.) *An element is a basic form of matter distinguished by special characteristics.* Each element has characteristics, or properties, that make it distinct, or different, from every other element. Examples of elements are iron, gold, silver, lead, carbon, copper, sulfur, oxygen, and hydrogen. The element, iron, for example, has properties that distinguish it from all other elements and the same is true of each of the 92 elements.

One outstanding property of elements is their stability. When an element enters into a chemical reaction it undergoes only a very slight change. It is true that the transmutation of one element into another element may be accomplished but such results require the application of very great energy. Under the usual conditions that exist in matter great stability

is the rule with nearly all of the elements. However, there are a few elements of unusual properties (the radioactive elements), which are changing spontaneously into other elements. Thus uranium and radium are constantly decomposing with the formation of simpler elements, and several other elements have this same power of spontaneously decomposing into simpler substances.

Symbol.—*A chemical symbol is an abbreviation of the name of an element.* It may be considered a unit of chemical shorthand, its purpose being to save the extra work of writing the whole name of the element. It usually is the first letter in the name, but as there are 92 discovered elements and only 26 letters in the alphabet, it is obvious that the initial letter cannot be used as an abbreviation in every case. When there are two or more elements whose names begin with the same letter, the practice is to use the first letter of the name for one element and, for the others, two significant letters of their name, usually the first two. In some instances we use a symbol derived from the Latin name given to the element by the alchemists. For example, the names and symbols of the four elements having the initial letter A are as follows: argon, A; aluminum, Al; arsenic, As; antimony, Sb. The first three symbols need no explanation; the fourth, Sb, is derived from stibium, the Latin word for antimony. Symbols are thus used for convenience and economy of expression in chemistry.

A symbol is not only a shorthand designation for an element, *but it also stands for a definite amount of the element.* The quantity of an element indicated by its symbol is the atomic weight of that element. (Atomic weights are discussed later.) For example, the symbol H not only stands for hydrogen, but it means an atomic weight of hydrogen, which is 1.0078 parts by weight; and the symbol O not only stands for oxygen, but it signifies an atomic weight of oxygen which is 16 parts by weight.

Compound and Mixture.—*A compound is a group of two or more elements firmly united in definite proportions. A mixture is a mass of two or more substances which are not*

combined firmly and need not be in any definite proportion. A compound differs from a mixture in the following ways:

1. In a compound the elements are definitely combined with each other; in a mixture the components are not combined, but are in loose contact with each other.

2. The elements of a compound are always present in the same proportion; the components of a mixture may be present in any proportion.

3. A mixture will exhibit the properties of each of its constituents; the properties of a compound will be different from those of its individual constituents.

To illustrate these distinctions, let us take the two elements, sulfur and iron, and grind each into very fine particles, and then mix them intimately. This mass of intermingled sulfur and iron particles is a mixture. The iron and sulfur are not firmly combined and can be separated easily by holding a magnet near the mass; a magnet will pick out the iron particles but will not attract the sulfur. Furthermore, either the sulfur or the iron may be present in any proportions. Now if we intermix, very thoroughly, 28 parts of iron and 16 parts of sulfur, and heat the mixture to a high temperature, the iron and sulfur will combine to form a compound, called iron sulfide. This compound will have quite different properties from either iron or sulfur; the iron and sulfur cannot be separated by a simple device like the magnet, and they are always present in the proportions of 28 parts of iron to 16 parts of sulfur.

Formula.—*A formula is an abbreviated expression for a compound.* It includes the symbols of all the elements in the compound, with subnumerals to show the number of atoms of each element present. For example, H_2O is the formula for water; this designation shows that a molecule of water contains two atoms of hydrogen and one atom of oxygen. To represent sulfuric acid, we use the formula, H_2SO_4, which is an abbreviated expression showing this compound contains 2 atoms of hydrogen, 1 atom of sulfur, and 4 atoms of oxygen in its molecule. The formula for cane sugar is $C_{12}H_{22}O_{11}$. The symbols C, H, and O show that

sugar contains the elements carbon, hydrogen, and oxygen, and each subnumeral (12, 22, or 11) indicates the number of atoms of the element immediately preceding it that are in a molecule of this substance. From these examples it is clear that the use of formulas shortens the work that would be required in writing out in full the names of compounds, and greatly reduces the space consumed in writing or printing chemical literature. Formulas are therefore a great convenience in chemistry, and the student will also find them an important aid to the memory in studying the many substances encountered in this subject.

The Atom.—When different kinds of matter react with each other and produce a chemical change, the process is called a chemical reaction. Chemical reactions are very orderly rearrangements of extremely minute particles of matter called atoms. *An atom is a basic structural unit of an element. It is a stable unit which takes part in all chemical changes and is not decomposed by the same.* When a chemical reaction takes place, the atoms are not decomposed but are torn away from, or made to combine with, atoms of other elements. For example, wood is a substance composed of many atoms of carbon, hydrogen, and oxygen, principally. When wood is burned, its atoms are torn apart and combined with atoms of oxygen from the air, and new substances are formed. The combustion of wood is a disruption of its substance down to the stage of the atom, but the atoms are not broken up. The latter are merely rearranged to form other substances—ashes and certain gases. The atom is thus seen to be a stable unit of matter which enters into chemical reactions involving energy changes and the formation, or decomposition, of compounds, but is not itself decomposed.

The Molecule.—*A molecule is a structural unit of matter.* In some instances the molecule consists of a single atom; thus mercury, sodium, potassium, argon, and helium are instances of elements whose molecule corresponds to the atom. The atoms of most elements, however, have a strong

tendency to combine, and, in doing so, they form molecules which consist of more than one atom.

Molecules may be composed of atoms of the same element or atoms of different elements. If composed of atoms of the same element, the molecule is a relatively simple structural unit, consisting usually of two atoms, though this number varies from one to eight. If composed of atoms of different elements, the molecule is a structural unit of the compound. The molecules of compounds are, as a rule, more complex than the molecules composed of atoms of a single element. The molecules of compounds contain from two to several thousand atoms.

Molecules are exceedingly small units of matter. They cannot be seen with the most powerful microscope. The diameter of a molecule of hydrogen has been estimated to be one ten-millionth of a millimeter.

Avogadro's Hypothesis.—The molecules of different gases vary in weight. For example, oxygen is 16 times heavier than hydrogen, and this difference in chemical nature may lead the student at first to think that a molecule of oxygen in the gaseous state will take up more space than a molecule of hydrogen. However, this is not the case. The molecules of gases are free to move about in space indefinitely, as we noted in establishing the distinctions between gases, liquids, and solids. As a result of this freedom of motion, the molecules of one gas will vibrate back and forth and take up the same space as the molecules of any other gas, regardless of size and weight. The only conditions that will change the space occupied by gases are temperature and pressure. When the temperature and pressure are the same, the molecules of every gas occupy the same space. This fact is summarized in the celebrated hypothesis of the Italian chemist, Avogadro, who, in 1811, advanced the theory that *in equal volumes of all gases under the same conditions of temperature and pressure there are equal numbers of molecules.* This hypothesis is the basis of some very important scientific deductions, as we shall see later.

Law of Definite Composition.—We have previously noted that one of the essential differences between a compound and a mixture is that the elements of a compound are always combined in definite proportions, while the mixture may have elements in any proportion. The fact that the elements in forming a compound always unite in the same manner and in the same ratios, is the basis of a fundamental law, the Law of Definite Composition. This law states that *a compound always contains the same elements united in the same manner and in the same proportions by weight.* Thus 2 parts by weight of hydrogen always combine with 16 parts by weight of oxygen to form 18 parts by weight of water. In the formation of water from hydrogen and oxygen, we cannot combine 2 parts of hydrogen with 10 parts of oxygen or 2 parts of hydrogen with 20 parts of oxygen, or make any other combination than that of 2 parts to 16 parts by weight. Water always has the same ratio of hydrogen to oxygen under any conditions, anywhere in the universe. The same law applies to all other compounds. We may change the proportions of the atoms in the molecule of a compound and produce a new compound, but, for the same compound, the proportions are always fixed and definite.

Combining Weights.—*When elements combine with each other, a definite weight of one element always combines with a definite weight of another element.* By chemical analysis the combining weight relationships between the elements may be determined, and it is important to have such information. To have combining weight values of the greatest usefulness, it is necessary to adopt some element as a standard and to set a definite amount of this element to be known as the standard for combining weights. This has been done. The element selected for this purpose is oxygen, and the amount of oxygen adopted as a standard for combining weights is 8 grams. *The combining weight of an element is the number of grams of that element that will combine with 8 grams of oxygen, or with an amount of another element that is chemically equivalent to 8 grams of oxygen.* The purpose of combining weights is to have established a definite

quantitative value that will stand for the combining ability of every element. If we want to know how many grams of one element will combine with a certain amount of another element, the answer is obtained by a simple calculation from the combining weights of the elements concerned. The establishment of 8 grams of oxygen as the standard for combining weights was arbitrary. Other standard values might have been used, but the use of 8 grams of oxygen as a standard has certain conveniences. This value for oxygen fixes the combining weight of hydrogen, the lightest element, at 1.0078; this is convenient because it avoids having values below 1 for any of the elements. The use of oxygen as a standard is also important because so many elements combine with oxygen, thereby affording a direct experimental method of determining the combining weights of these elements.

The combining weight relationships of the elements can be explained best by taking up a few examples. Let us consider the following data:

In water,	H_2O,	1.0078	gm.	hydrogen	combine	with	8	gm.	oxygen
In chlorine monoxide,	Cl_2O,	35.45	"	chlorine	"	"	8	"	"
In sodium oxide,	Na_2O,	23	"	sodium	"	"	8	"	"
In calcium oxide,	CaO,	20	"	calcium	"	"	8	"	"
In carbon dioxide,	CO_2,	3	"	carbon	"	"	8	"	"

The amounts of hydrogen, chlorine, sodium, calcium, and carbon that will combine with 8 grams of oxygen, which by definition are the combining weights of these elements, are indicated. The importance of these figures is that they not only show the combining values of certain elements for oxygen, but they also indicate the amounts of these elements that will be used when they combine with each other, or with the combining weight of any other element. Thus the amount of chlorine combining with 8 grams of oxygen is 35.45 grams; this amount of chlorine will also combine with 1.0078 grams of hydrogen, or 23 grams of sodium, or 20 grams of calcium, or 3 grams of carbon.

Law of Multiple Proportions.—There are many instances where two elements unite to form more than one compound. When they do this, different proportions by weight of the elements entering into the formation of the compounds are involved. The following are examples:

COMPOUNDS		COMBINING PROPORTIONS BY WEIGHT
Cupric oxide,	CuO	Cu : O = 63 : 16
Cuprous oxide,	Cu_2O	Cu : O = 126 : 16
Mercuric oxide,	HgO	Hg : O = 200 : 16
Mercurous oxide,	Hg_2O	Hg : O = 400 : 16
Nitrous oxide,	N_2O	N : O = 14 : 8
Nitric oxide,	NO	N : O = 14 : 16
Nitrogen trioxide,	N_2O_3	N : O = 14 : 24
Nitrogen dioxide,	NO_2	N : O = 14 : 32
Nitrogen pentoxide,	N_2O_5	N : O = 14 : 40

Inspection of the above data shows an interesting relationship. Let us consider first the two oxides of copper. The difference in these two compounds is that the first one contains by weight 63 parts of copper to 16 parts of oxygen, and the second one contains by weight 126 parts of copper to 16 parts of oxygen. The ratio of the amount of copper in the first compound to the amount of copper in the second compound is 63 : 126, or 1 : 2. The change in the amounts of the varying element, copper, is thus represented by whole numbers.

A similar relationship is shown by the two oxides of mercury. In mercuric oxide the ratio by weight of mercury to oxygen is 200 : 16; in mercurous oxide the ratio by weight of mercury to oxygen is 400 : 16. In these compounds the variation in the amount of mercury present is 200 : 400, or 1 : 2, which again is a whole number ratio.

In the third group of compounds there are still more interesting examples of whole number variations in one of the elements. Thus in the column showing the amount of oxygen, it will be seen that the proportions of oxygen by weight in the second column are as 8 : 16 : 24 : 32 : 40, or 1 : 2 : 3 : 4 : 5. Here again we find a simple whole number relationship in the amounts of the varying element (oxygen) in these five compounds.

With the above data in mind the student can now readily understand the law of multiple proportions. This law states that *when two elements form more than one compound with each other, a simple whole number relationship exists in the proportions of the element whose amounts are varied.*

The student will at once see that the law of multiple proportions is a very obvious and very reasonable principle. If a variation in the elements of a compound occurs, this will not be in terms of half of an atom, or a quarter of an atom, or fractions of an atom; whatever change occurs must necessarily be in terms of whole atoms. Therefore, when the proportions between the elements of a compound are changed, the ratio between the amounts of the varying element must be a ratio of whole numbers.

Atomic Weights.—*Atomic weights are relative weights of atoms of the elements. An atomic weight of an element is a value which represents the weight of an atom of that element when compared with the weight of an atom of oxygen, which has been arbitrarily set at 16.* For example, the atomic weight of hydrogen is approximately 1; of oxygen, 16; of iron, 55. These numbers have a relative significance. They mean that an atom of oxygen is 16 times heavier than an atom of hydrogen; that an atom of iron is 55 times heavier than an atom of hydrogen; also that the ratio of the weight of an atom of iron to an atom of oxygen is as 55 is to 16. Again, uranium, the heaviest of all the elements, has an atomic weight of 238. This figure means that the ratio of the weight of an atom of uranium to an atom of iron is as 238 is to 55; to an atom of oxygen is as 238 is to 16; and to an atom of hydrogen is as 238 is to 1.

Hydrogen was once taken as the standard for atomic weight values, and was given the atomic weight of 1. Later it was found more convenient to use oxygen as a standard. When oxygen was adopted as a standard and given the value of 16, the value for hydrogen changed from 1 to 1.0078. The atomic weights of the elements are given in the table on the inside page of the front cover.

Molecular Weights.—*Molecular weights are relative weights. A molecular weight is a value that represents the weight of a molecule of one substance as compared with the weight of a molecule of another substance.* The molecular weight of a substance is the sum of the atomic weights of the elements in its molecule. The hydrogen molecule (H_2) contains two atoms; therefore, the molecular weight of hydrogen is twice the atomic weight (1.0078 × 2), or 2.016. Since the atomic weight of oxygen is 16 and the oxygen molecule contains two atoms, the molecular weight of oxygen is 32 (16 × 2). If we know the formula of a compound, we can calculate its molecular weight by taking the sum of the atomic weights of all the elements in the molecule. This is illustrated by the following examples:

For Water, H_2O:

Atomic	weight	of	2 H =	2.016
"	"	"	O =	16.000
Molecular	"	"	H_2O =	18.016

For Sodium chloride, NaCl:

Atomic	weight	of	Na =	23.0
"	"	"	Cl =	35.5
Molecular	"	"	NaCl =	58.5

For Sulfuric acid, H_2SO_4:

Atomic	weight	of	2 H =	2.016
"	"	"	S =	32.06
"	"	"	4 O =	64.000
Molecular	"	"	H_2SO_4 =	98.076

In the foregoing illustrations we assumed that the formula is known and proceeded with this information in mind to calculate the molecular weight. But what if the formula is not known? Here is where we turn to the experiments of the laboratory, which are the basis of all chemical deductions. Experimentally, there are several methods of determining molecular weights. In principle, the simplest of these methods is to compare the weight of a certain amount of substance in the gaseous state with an equal volume of oxygen at the same temperature and pressure. For example, it has

been found experimentally that 22.4 liters of oxygen weigh 32 grams at 0° Centigrade and a pressure of one atmosphere. At the same temperature and pressure, 22.4 liters of hydrogen weigh 2.016 grams. Therefore, the ratio of the weight of oxygen to that of hydrogen is as 32 is to 2.016. Now in comparing 22.4 liters of oxygen with 22.4 liters of hydrogen, we are comparing equal numbers of molecules, since by Avogadro's hypothesis there are equal numbers of molecules in equal volumes of gases at the same temperature and pressure. This is the same as comparing the weight of one molecule of oxygen with the weight of one molecule of hydrogen. Therefore, since the molecular weight of oxygen is taken as 32 for a standard, the molecular weight of hydrogen is 2.016. In a similar manner, we may determine the molecular weight of any other substance in the gaseous state. These principles are shown graphically in Fig. 2, page 45.

Chemical Reaction—Affinity.—Why does a chemical reaction take place? This is perhaps one of the first questions that comes into the mind of the beginning student of chemistry. The immediate, though not ultimate, explanation of this question is a difference in what is called chemical "affinity." *Chemical affinity is the force of attraction between the atoms of the elements which causes them to combine and form compounds.* All other things being favorable, atoms, when brought together, will combine if there is sufficient chemical affinity between them.

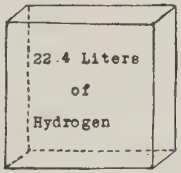
The chemical affinity of the different elements varies widely. Some elements will combine with other elements readily; others will combine if influenced by heating or other procedures; and six elements—helium, neon, argon, xenon, krypton, and radon—will not combine at all. It is this variation in chemical affinity which has made possible the existence and the preparation of so many chemical compounds. In general, elements of opposite chemical nature, e.g., metals and non-metals, have an affinity for each other, and will combine to form compounds.

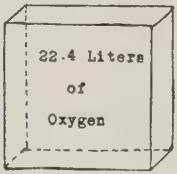
Chemical affinity, of course, cannot operate unless the atoms are brought in close contact. For this reason, in car-

rying out chemical reactions, we mix the substances intimately and often introduce such procedures as heating, or dissolving in water, which serve to remove the atoms from their existing combination and to bring them in close contact with the atoms of other elements, thereby providing the possibility for the formation of new compounds. In a chemical reaction the final results are as follows:

1. The atoms which have the greatest affinity or attraction for each other combine and form a compound.

2. If there are other atoms remaining in the field of the reaction, they combine with the atoms of that element for which they have the strongest affinity.





Absolute weight = 2.016 grams
Molecular weight of
hydrogen = 2.016

Absolute weight = 32 grams
Molecular weight of
oxygen = 32

Fig. 2.—Diagram illustrating method of determining molecular weights.

3. If there are no more atoms of other elements in the field of the reaction, the remaining atoms of the same element combine with each other, in most instances.

This behavior is illustrated by the following scheme:

$$1.\ AB + CD \rightarrow AD + BC$$
$$2.\ 2\,AB + 2\,C \rightarrow 2\,AC + B_2$$

In the first reaction, the element A, has a stronger affinity for D than for B; consequently, it leaves B and becomes attached to D, forming a new compound, AD. B and C, being left in the field, and having some chemical affinity for each other, combine and form another compound, BC. In the second reaction, A has a stronger affinity for C than for B; A, therefore, combines with C. Being left alone, B combines with itself.

An explanation of the underlying principles regarding chemical affinity cannot be given until the structure of the atom has been studied. This will be taken up later in the chapter on the Structure of Matter (Chapter V).

The Equation.—*The equation is an abbreviated expression for a chemical change.* It is a further application of the shorthand system of the chemist. Just as the symbol is an abbreviation for an element, and the formula is an abbreviation for a compound, so the equation may be considered a shorthand method of indicating a complete chemical reaction in which symbols and formulas are used. For example, we may represent the reaction between zinc and hydrochloric acid very briefly as follows:

$$\underset{\text{Zinc}}{Zn} + \underset{\text{Hydrochloric acid}}{2\,HCl} \rightarrow \underset{\text{Zinc chloride}}{ZnCl_2} + \underset{\text{Hydrogen}}{H_2}$$

The above is a completed chemical equation. It shows that when zinc and hydrochloric acid are mixed, zinc chloride and hydrogen are produced; one atom of zinc reacts with two molecules of hydrochloric acid to form one molecule of zinc chloride and one molecule of hydrogen; the number of atoms of zinc, hydrogen, and chlorine on one side is exactly equal to the number of the same atoms on the other; the sum of the weights of the zinc and hydrochloric acid on the left is equal to the sum of the weights of the zinc chloride and hydrogen on the right. Instead of reading this long dissertation upon the reaction of zinc with hydrochloric acid, the student, when trained, can get the same thought from the equation, which stands for it, with greater clearness and rapidity.

It is important to note that an equation always stands for some reaction which has previously been carried out and proved by experiment. We do not work equations with our imagination, but by knowledge first obtained in the laboratory. We treat certain substances chemically and, from our observations, we write out equations to represent the results as we find them. The laboratory experiment is always the basis of a chemical equation.

Types of Chemical Reactions.—Practically all chemical reactions will come under one of the four following types:

1. *Combination, or Synthesis.*

Example:

$$C + O_2 \rightarrow \underset{\text{Carbon dioxide}}{CO_2}$$

This requires little explanation. Carbon and oxygen have an affinity for each other, and, consequently, they will combine and form the compound carbon dioxide.

2. *Decomposition, or Analysis.*

Example:

$$\underset{\substack{\text{Potassium}\\\text{chlorate}}}{2\ KClO_3} \xrightarrow{\text{heat}} \underset{\substack{\text{Potassium}\\\text{chloride}}}{2\ KCl} + \underset{\text{Oxygen}}{3\ O_2}$$

In this reaction the force of chemical attraction between the atoms of potassium chlorate is overcome by heating to a high temperature, and the result is a decomposition with the liberation of oxygen and the formation of potassium chloride.

3. *Double Decomposition, or Metathesis.*

Example:

$$\underset{\substack{\text{Silver}\\\text{nitrate}}}{AgNO_3} + \underset{\substack{\text{Hydrochloric}\\\text{acid}}}{HCl} \rightarrow \underset{\substack{\text{Silver}\\\text{chloride}}}{AgCl} + \underset{\substack{\text{Nitric}\\\text{acid}}}{HNO_3}$$

Here the atoms exchange places because there is greater affinity between the elements in the new combinations to the right of the arrow.

4. *Replacement, or Substitution.*

Example:

$$\underset{\substack{\text{Hydrochloric}\\\text{acid}}}{2\ HCl} + \underset{\text{Zinc}}{Zn} \rightarrow \underset{\substack{\text{Zinc}\\\text{chloride}}}{ZnCl_2} + \underset{\text{Hydrogen}}{H_2}$$

This reaction is an example of an element with stronger affinity for another element replacing the element with less

affinity. Zinc, having a stronger affinity for chlorine than hydrogen, replaces the latter. There being no other elements with which to combine, the hydrogen atoms combine with themselves, forming molecules containing 2 atoms.

In all of these reactions it is to be noted that chemical affinity is the underlying principle which determines what the results will be.

Reversible Reactions—Equilibrium.—In the discussion of types of chemical reactions above the reaction symbol (arrow) was made to point to the right, indicating that only the products on the right are formed. This is correct. Practically, the reaction goes to completion toward the right because one of the products is removed from the field of reaction. Thus in the third equation, the reaction goes to the right because the AgCl is highly insoluble and after its formation does not react appreciably with the HNO_3 to form the products on the left of the reaction symbol.

Again, in equation number 4, the substances on the right of the arrow are the only products of the reaction because hydrogen is a gas and is practically removed from the presence of the $ZnCl_2$. It is satisfactory to write this equation with the arrow pointing to the right.

Both equations 3 and 4 are examples of one-way reactions. All chemical reactions are not like this. For example, in the following reaction

$$2\ NaCl + H_2SO_4 \rightarrow 2\ HCl + Na_2SO_4$$

it is indicated that the substances on the left of the arrow react with each other to produce the substances on the right. However, it is true that the substances on the right of the arrow react to a certain extent with each other to give the substances on the left. To indicate the facts fully, we, therefore, write this equation with the arrows pointing in both directions.

$$2\ NaCl + H_2SO_4 \rightleftarrows 2\ HCl + Na_2SO_4$$

This we speak of as a reversible reaction. After allowing adequate time, one will find that the amounts of the sub-

stances on each side of the arrows finally become constant, and we say a state of equilibrium exists. In an equilibrium state there are two opposing changes taking place and, after enough time has elapsed, the amount of change in one direction is equal to the amount of change in the other direction.

For those reactions which go one way, we write the reaction symbol pointing toward the products formed; for those reactions which are reversible, we write our reaction symbols pointing both ways.

Radical.—Sometimes, in chemical reactions, two or more atoms remain together and behave as one atom. Such a group of atoms is called a *radical.* Examples of radicals are:

SO_4 group in H_2SO_4 (sulfuric acid)
NO_3 group in HNO_3 (nitric acid)
OH group in NaOH (sodium hydroxide).

In most chemical reactions, these groups remain intact; that is, their atoms apparently do not separate and at the end of the reaction they are found combined in the same manner.

Valence.—The word "valence" comes from a Latin word meaning strength. In chemistry it signifies the combining strength or combining requirement of an element. More specifically, *valence is a number which tells how many atoms of one element are required to combine with an atom, or atoms, of another element when a compound containing both elements is formed.* For each of the 92 elements there is a number which represents the combining requirement of that element when uniting with other elements, and this number is known as the valence of the element. The valences of all of the elements are included in the numbers ranging from 0 to 8.

There are six elements—helium, argon, neon, xenon, krypton, and radon—which do not combine with other elements. In other words, these elements exist only in the free state and do not form compounds. The valence of these six elements is 0.

A very considerable number of elements have a valence of 1. Among these elements is hydrogen. One atom of hy-

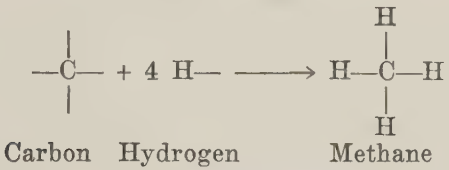
drogen will require only one atom of another element with a valence of 1 in forming a compound. By similar reasoning it follows that in any compound in which hydrogen is combined with another element, if only one atom of hydrogen is required to unite with one atom of the second element, the valence of the second element is 1. To illustrate, let us take the compound HCl. We know that the valence of hydrogen is 1. Therefore, since only one atom of hydrogen is found combined with one atom of chlorine, the valence of chlorine is 1. *Since hydrogen has a valence of 1 and combines with many other elements, it has been found desirable to use this element as a reference standard of valence.*

From the foregoing discussion of hydrogen it is obvious that one atom of any element with a valence of 1 will combine with one atom of another element having a valence of 1. The elements, sodium, potassium, chlorine, and iodine, have a valence of 1. In forming compounds, these elements combine in the ratio of one to one, as, for example, NaCl, KCl, NaI, KI.

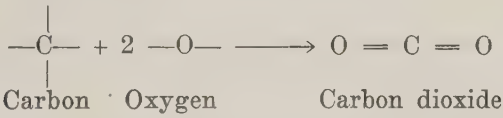
Oxygen is a good example of an element with a valence of 2. When oxygen combines with hydrogen, it forms water, H_2O. In endeavoring to establish the valence of oxygen, the student needs only to observe that in water one atom of oxygen is combined with 2 atoms of hydrogen. As the valence of hydrogen is 1, it follows that the valence of oxygen must be 2, because oxygen requires 2 hydrogen atoms to satisfy its combining requirements. To carry our analysis further, we will raise the question: What is the valence of mercury in the compound HgO? We know from what has just been stated that oxygen has a valence of 2. Therefore, the valence of mercury is 2, since one atom of oxygen is combined with one atom of mercury.

When the element nitrogen combines with hydrogen, it forms the compound ammonia, NH_3. The student will readily observe from the formula for ammonia that the valence of nitrogen is 3, because it combines with three atoms of hydrogen.

Carbon is an element whose valence is 4. In entering into chemical combination with hydrogen, one atom of carbon unites with four atoms of hydrogen to form the compound methane, CH_4. We can see this more easily if we write an equation showing each of the elements with a dash, or "bond," to represent each of its valences. Thus



Again, let us use carbon for an exercise in the application of valence. What should be the formula of a compound containing carbon and oxygen? Since carbon has a valence of 4 and oxygen a valence of 2, two atoms of oxygen will be required to unite with one atom of carbon, forming the compound carbon dioxide, CO_2. The equation for this chemical reaction is as follows:



Now let us undertake a slightly more difficult application of the principles of valence. What is the formula for a compound of iron (Fe) and oxygen (O)? Here the student will have to examine the formulas of some simpler known compounds of these elements. Looking for simpler compounds of iron, the student will come upon the substance, ferric chloride, $FeCl_3$. It is at once obvious that the valence of Fe is 3, since Fe is combined with 3 chlorine atoms and, as we noted, chlorine has a valence of 1 because it has been found to combine with hydrogen in a 1:1 ratio (HCl). In a similar manner it is ascertained that oxygen has a valence of 2 (see discussion of oxygen in H_2O). Now Fe and O cannot be put together in a 1:1 ratio, as their valences, 3 and 2, respectively, do not balance each other. Trying other

combinations, we soon hit upon the formula Fe_2O_3, which is correct; but let us prove its correctness by the following deductions:

3 (the valence of Fe) × 2 (atoms of Fe) = 6 (total valences of Fe_2)
2 (the valence of O) × 3 (atoms of O) = 6 (total valences of O_3)

The formula Fe_2O_3 is thus seen to be correct, as the total valences of the two elements of the molecule (6) are the same and each element satisfies the combining requirement of the other element.

Valences of 5, 6, 7, and 8 are exhibited by other elements. But these need not be discussed here, as the principles involved are the same as those mentioned above.

The principles of valence outlined for individual elements apply also to radicals. Take, for example, the three compounds, HNO_3 (nitric acid), Na_2SO_4 (sodium sulfate), and K_3PO_4 (potassium phosphate). In the first compound the valence of the NO_3 radical is 1, because it requires one hydrogen atom to satisfy its combining requirements. Similarly, in the compound, Na_2SO_4, the valence of the SO_4 radical is 2, because two atoms of the element sodium, whose valence is 1, enter into combination with this radical; and in K_3PO_4, the valence of the PO_4 radical is seen to be 3, as this radical is combined with three atoms of potassium, a monovalent element.

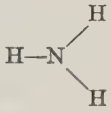
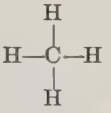
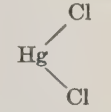
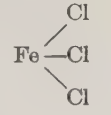
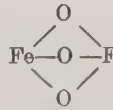
Some elements have more than one valence. Mercury, for example, is an element having two valences. Under oxidizing conditions the mercury atom assumes a valence of 2, while under reducing conditions the mercury atom has a valence of 1. Mercury may, therefore, form two compounds with chlorine. Exhibiting a valence of 2, mercury forms the compound mercuric chloride ($HgCl_2$); and manifesting a valence of 1, mercury forms the compound mercurous chloride (HgCl).

The student need not let variations in valence be disturbing. The conditions determining valence are easily understood when a more advanced knowledge of chemistry has been obtained. At this point it is quite satisfactory to realize that variations in valence exist without questioning

the reasons for these variations. In this connection it is important to note, however, that the elements, in forming compounds, always exhibit a definite valence, or combining requirement, which is another way of stating the Law of Definite Composition. Whenever an element manifests another valence it is always due to a change in the chemical

TABLE I

VALENCE AND ITS APPLICATION TO FORMULA WRITING

ELEMENTS	VALENCE	COMPOUNDS	GRAPHIC REPRESENTATION
Hydrogen Chlorine	1 1	HCl Hydrochloric acid	H—Cl
Hydrogen Oxygen	1 2	H_2O Water	H—O—H
Hydrogen Nitrogen	1 3	NH_3 Ammonia	
Hydrogen Carbon	1 4	CH_4 Methane	
Mercury Chlorine	1 1	HgCl Mercurous chloride	Hg—Cl
Mercury Chlorine Oxygen	2 1 2	$HgCl_2$ Mercuric chloride HgO Mercuric oxide	 Hg=O
Iron Chlorine Oxygen	3 1 2	$FeCl_3$ Ferric chloride Fe_2O_3 Ferric oxide	 

conditions under which the element is placed. *For any given set of conditions the valence of an element is constant, and when we know these conditions, we can apply our knowledge to writing formulas for compounds with absolute certainty.*

TABLE II

VALENCE OF SOME ELEMENTS

ELEMENT	VALENCE
Aluminum	3
Antimony	3 or 5
Arsenic	3 or 5
Barium	2
Bismuth	3 or 5
Boron	3
Bromine	1, 3, 5, or 7
Calcium	2
Carbon	2, 3, or 4
Chlorine	1, 3, 5, or 7
Copper	1 or 2
Fluorine	1
Gold	1 or 3
HYDROGEN	1
Iodine	1, 3, 5, or 7
Iron	2 or 3
Lead	2 or 4
Lithium	1
Magnesium	2
Manganese	2, 4, 6, or 7
Mercury	1 or 2
Nitrogen	3 or 5
Oxygen	2
Phosphorus	3 or 5
Platinum	2 or 4
Potassium	1
Silicon	4
Silver	1
Sodium	1
Sulfur	2, 4, or 6
Tin	2 or 4
Uranium	4 or 6
Zinc	2

From the above, it is evident that *the practical value of a knowledge of valence is that it enables one to write the formulas of compounds and work chemical equations.* In practice we show the valence of the elements in a compound by writing the formula for the compound graphically, and indicating each valence by a short line, or "bond," drawn be-

tween the elements. (See Table I, page 53.) The student will do well to visualize valence as a bond, or bonds, of attraction between the elements of a compound.

An explanation of the underlying conditions which determine valence will be given later, in the chapter on the Structure of Matter (V).

Questions for Study

1. What did the early philosophers believe were elementary substances?
2. What is an element? How many elements exist in the matter composing the earth?
3. What is a symbol? Of what value is it?
4. What is a compound? Distinguish between a compound and a mixture.
5. What is a formula? Illustrate by examples. What is the purpose of formulas?
6. What is an atom? What part does the atom play in chemical changes?
7. What is a molecule? What is the relation of molecules to atoms?
8. What is Avogadro's hypothesis?
9. Define atomic weights.
10. Define molecular weights.
11. Calculate the molecular weights of the following compounds, using the table of atomic weights on the inside page of the front cover: hydrochloric acid, HCl; sodium hydroxide, NaOH; potassium nitrate, KNO_3; calcium sulfate, $CaSO_4$; magnesium sulfate, $MgSO_4$.
12. Explain the Law of Definite Composition.
13. What is chemical affinity? Why do chemical reactions take place?
14. What is an equation? What is its purpose?
15. What are the four types of chemical reactions? Explain each.
16. What is a radical?
17. What is a reversible reaction?
18. What is meant by equilibrium in a chemical reaction?
19. What is meant by valence? What element is used as a standard for valence? What is the value of a knowledge of valence?

CHAPTER III

NAMING OF CHEMICAL COMPOUNDS

Without some system of nomenclature it would be a difficult task for the student of chemistry to learn the names of the many known chemical substances. It is, therefore, important for the beginning student to get in mind some of the simpler rules that are followed in naming the many compounds known to chemistry.

Naming of Binary Compounds.—The word binary means two. Binary compounds contain two elements. A binary compound is given a name which includes the names of both of its elements. The practice is to place the name of the metallic element first and to follow it with the name of the non-metallic element, which is modified by changing its last syllable to *ide.*

Examples:

ELEMENTS IN COMPOUND	NAME OF COMPOUND FORMED
Sodium and chlorine	Sodium chloride
Iron and sulfur	Iron sulfide
Potassium and iodine	Potassium iodide
Calcium and oxygen	Calcium oxide

Where two elements form more than one compound with each other it becomes necessary to have distinguishing names for the different compounds. One rule to take care of this situation is to change the suffix of the name of the varying element to *"ous" in the compound in which this element has the lower valence and to "ic" in the compound in which it has the higher valence.*

Examples:

$HgCl$ —Mercur*ous* chloride (valence of mercury = 1)
$HgCl_2$—Mercur*ic* chloride (valence of mercury = 2)

Cu_2O —Cupr*ous* oxide (valence of copper = 1)
CuO —Cupr*ic* oxide (valence of copper = 2)

$FeCl_2$ —Ferr*ous* chloride (valence of iron = 2)
$FeCl_3$—Ferr*ic* chloride (valence of iron = 3)

Another practice for distinguishing between compounds of the same two elements is to use the prefixes *mono-, di-, tri-, tetr-, pent-,* etc., which mean one, two, three, four, and five, respectively, the prefix used being appropriate to designate the number of atoms of the varying element in the molecule.

Examples:

CO — Carbon *mon*oxide
CO_2 — Carbon *di*oxide

NO_2 — Nitrogen *di*oxide
N_2O_4 — Nitrogen *tetr*oxide

PCl_3 — Phosphorus *tri*chloride
PCl_5 — Phosphorus *penta*chloride

A variation of the last mentioned rule is found in the use of the suffix *per* for *di.*

Examples:

H_2O_2 — Hydrogen *per*oxide
Na_2O_2 — Sodium *per*oxide

Naming of Inorganic Acids.—

1. *Hydro Acids.*—All acids contain hydrogen, and most acids contain oxygen. The acids that do not contain oxygen are given the prefix *hydro* to distinguish them from the oxyacids. The prefix hydro is followed by the name of the non-metallic element (or elements) of which the acid is composed, the last part of the name being modified to include the suffix *ic.*

Examples:

HCl — *Hydro*chloric acid
HCN — *Hydro*cyanic acid
H_2S — *Hydro*sulfuric acid

2. *Oxyacids.*—The oxyacids contain oxygen and hydrogen in addition to a non-metallic element (or elements). The practice in naming oxyacids is to give an acid of this group a name derived from that of the non-metallic element which enters into its composition.

Examples:

H_2SO_4 — Sulfuric acid (oxyacid containing sulfur)
HNO_3 — Nitric acid (oxyacid containing nitrogen)
H_3PO_4 — Phosphoric acid (oxyacid containing phosphorus)
H_2CO_3 — Carbonic acid (oxyacid containing carbon)

A number of oxyacids exist which are composed of the same elements but vary in their oxygen content. In these cases it becomes necessary to introduce variations in suffixes and prefixes in order to get distinguishing names. We first apply the suffixes *ic* and *ous*. To the acid containing the greater amount of oxygen in its molecule is given a name ending in *ic;* to the one containing the lesser amount of oxygen in its molecule is given a name ending in *ous*. If more than two oxyacids of the same elements exist, the prefixes *per* and *hypo* are used. *Per* is prefixed to the name of the acid containing more oxygen than the *ic* acid; and *hypo* is applied to the name of the acid containing less oxygen than the *ous* acid.

Examples:

HNO_3 — Nitr*ic* acid	HClO — *Hypo*chlor*ous* acid
HNO_2 — Nitr*ous* acid	$HClO_2$ — Chlor*ous* acid
H_2SO_4 — Sulfur*ic* acid	$HClO_3$ — Chlor*ic* acid
H_2SO_3 — Sulfur*ous* acid	$HClO_4$ — *Per*chlor*ic* acid

Naming of Bases.—A base contains a metallic element combined with an OH or hydroxyl radical. The practice in naming a base is to use the unchanged name of the metallic element of which it is composed, followed by the term *hydroxide*.

Examples:

NaOH — Sodium hydroxide
KOH — Potassium hydroxide
$Ca(OH)_2$ — Calcium hydroxide
NH_4OH — Ammonium hydroxide

Some base-forming elements manifest two valences in entering into combination with the hydroxyl radical. In these instances the same rule is followed as related above: apply the suffix *ous* where the lower valence is exhibited and *ic* where the higher valence is found.

Examples:

CuOH — Cupr*ous* hydroxide	(valence of Cu = 1)
$Cu(OH)_2$ — Cupr*ic* hydroxide	(valence of Cu = 2)
$Fe(OH)_2$ — Ferr*ous* hydroxide	(valence of Fe = 2)
$Fe(OH)_3$ — Ferr*ic* hydroxide	(valence of Fe = 3)

Naming of Salts.—The name of a salt is derived from the names of the acid and base from which it is prepared. The first part of the name of a salt is the unaltered name of the metallic element of the base from which it is derived; the second part is the name of the non-metallic element, or radical of the acid from which it is made, with a modified suffix. If it is a salt of a hydro acid, the prefix hydro is dropped and its name ends with the suffix *ide*. If it is derived from an oxyacid, its name ends in *ate* when the parent acid is an *ic* acid and in *ite* when the parent acid is an *ous* acid.

Examples:

KCl — Potassium chloride—a salt formed from potassium hydroxide (KOH) and hydrochloric acid (HCl)

Na_2SO_4 — Sodium sulf*ate*—a salt formed from sodium hydroxide ($NaOH$) and sulfur*ic* acid (H_2SO_4)

Na_2SO_3 — Sodium sulf*ite*—a salt formed from sodium hydroxide and sulfur*ous* acid (H_2SO_3)

$NaC_2H_3O_2$— Sodium acet*ate*—a salt formed from sodium hydroxide and acet*ic* acid ($HC_2H_3O_2$)

$NaClO_2$ —Sodium chlor*ite*—a salt formed from sodium hydroxide and chlor*ous* acid ($HClO_2$)

$NaClO_4$ — Sodium perchlor*ate*—a salt formed from sodium hydroxide and perchlor*ic* acid ($HClO_4$)

Some metallic elements enter into the formation of more than one salt because of a variation in their valence. In these instances the same rule is applied as was used above where two valences are exhibited. For the salt in which the higher valence of the metallic element is manifested, the suffix *ic* is used; and for the salt in which the metal has the lower valence, the suffix *ous* is used.

Examples:

$HgNO_3$ —Mercur*ous* nitrate
$Hg(NO_3)_2$—Mercur*ic* nitrate

$FeSO_4$ —Ferr*ous* sulfate
$Fe_2(SO_4)_3$ —Ferr*ic* sulfate

Questions for Study

1. What is the general rule for naming binary compounds?
2. Where two elements form more than one compound with each other, how are the compounds given distinguishing names?
3. What is the general rule for naming hydro acids? Oxyacids?
4. What is the general rule for naming bases?
5. Where two bases of the same metallic element occur, what is the practice in naming?
6. What is the general rule for naming salts?
7. A salt of an *ic* acid ends in what suffix? A salt of an *ous* acid ends in what suffix?

CHAPTER IV

THE PERIODIC LAW AND ATOMIC NUMBERS

The Periodic Law.—The periodic law was first clearly announced by Mendeléeff in 1869. It has been modified somewhat since its appearance as a result of growth in knowledge of the elements, but the general principles laid down by Mendeléeff still hold good. The periodic law, as stated by Mendeléeff, is as follows: The properties of the elements are periodic functions of their atomic weights. This law means that, if the elements are arranged in the order of their atomic weights and grouped into periods, elements with similar physical and chemical properties recur at definite intervals.

To enable the student to understand this law, we will first illustrate how it was developed. If we omit hydrogen, which does not fit into this law, and place the next eight elements in a row in the order of their atomic weights, we will have an arrangement of these elements corresponding to the first period of the periodic table on the inside page of the back cover. This we will do as follows:

Helium	Lithium	Beryllium	Boron	Carbon	Nitrogen	Oxygen	Fluorine
4.00	6.94	9.02	10.82	12.00	14.00	16.00	19.00

Similarly, if we arrange the next eight elements in the same way, we will have the second period of the periodic table, which is as follows:

Neon	Sodium	Magn'm	Aluminum	Silicon	Phosphorus	Sulfur	Chlorine
20.18	22.99	24.32	26.97	28.06	31.02	32.06	35.45

Proceeding in like manner one may arrange all of the elements according to their atomic weights in periods as Mendeléeff did and thus produce a table somewhat like that on the inside page of the back cover.

Now the great advantage of such an arrangement as the periodic table is that it places the elements in groups which

have many similarities in properties. These related groups are the ones in the vertical columns formed by drawing lines between each vertical row of elements. The periodic table is thus an arrangement of all of the elements in related groups or families. This arrangement shows a very striking relationship of each of the elements to the place it occupies in the table. In fact, the periodic table is so significant an arrangement that it is now recognized that each place in it defines the properties of the element which belongs to that place.

Atomic Numbers.—In the periodic table of Mendeléeff the elements are arranged in the order of their atomic weights, as just indicated above. In most instances this order of arrangement gives a significant relationship, but there are six elements whose properties do not agree with what might be expected from the place they occupy in this table. Following the announcement of the periodic law, it became evident that a different basis for arranging the elements in the periodic table would be desirable. Chemists who had studied the properties of the elements had such faith in the periodic grouping of elements according to their properties that they altered the order of the table of Mendeléeff so that each element would fall in a place that would suit its properties. In the modified arrangement hydrogen, the lightest element, is element Number 1; helium is element Number 2; lithium is element Number 3; and so on up to uranium, the heaviest element, which is element Number 92. Each element is given a serial number corresponding to the place in the periodic table that it should occupy according to its properties. This serial number given to each element was called the atomic number.

The abandonment of atomic weights as the fundamental basis for the arrangement of the periodic table was found to be amply justified by a study of x-rays which showed that the atomic number actually represents a fundamental quantity in the atom. It was found that when electric discharges in a vacuum tube are directed upon different solid

elements as targets, x-rays are emitted whose wave lengths vary according to the atomic numbers of the elements, but do not vary according to the atomic weights in all cases. The behavior of the elements with respect to x-rays was thus shown to vary according to an atomic number arrangement. Other experimental facts have been brought forth to justify the establishment of atomic numbers, but this brilliant demonstration is all that need be mentioned here.

The assigning of a serial number to each element is not a radical change from the old order of the periodic table based upon atomic weights. In all but three places the orders of atomic weights and atomic numbers are the same. The exceptions are where argon and potassium, cobalt and nickel, and tellurium and iodine are placed. An examination of the table on the inside page of the back cover will show that these elements are not placed in the order of their atomic weights. This is because their properties do not agree with such an arrangement. For instance, in the case of potassium (atomic weight 39.09) and argon (atomic weight 39.91), the properties of argon require that it be placed before potassium in the periodic table which is not in agreement with an ascending order of atomic weights. Here an arrangement according to atomic numbers, making argon element Number 18 and potassium element Number 19, agrees best with the properties of these two elements. Similarly, in the other two exceptions to the order of atomic weights, the periodic table becomes more consistent when the elements are arranged in the order of their atomic numbers.

With the establishment of atomic numbers on a firm basis, the periodic law was no longer stated in relation to atomic weights as Mendeléeff expressed it. The change in the law was the substitution of atomic numbers for atomic weights. The law in its modern form is stated as follows: *The ordinary physical and chemical properties of the elements are periodic functions of their atomic numbers.* The periodic table as given on the inside page of the back cover is an arrangement of the elements according to their atomic numbers.

Having presented the development of the periodic system, we shall now discuss some very important generalizations that are made from it.

Natural Families.—Grouping the elements in periods places them in an arrangement in which the vertical columns are natural families. In the first column (Group 0) on the left side of the table (see the inside page of the back cover) we find the rare gases, consisting of helium, neon, argon, krypton, xenon, and radon. These elements are very stable; they do not combine chemically; their valence is zero; and they have other similar characteristics, thus making a natural family. In the second group from the left (Group I) is the alkali family, composed of lithium, sodium, potassium, rubidium, and cesium; these elements have similar characteristics and form another natural family. In Group VII we find the halogen family, consisting of fluorine, chlorine, bromine, and iodine. Similarly, in each of the vertical columns of the periodic table we find families of elements related in properties. This division of the elements into natural families is of great value in enabling one to become familiar with the characteristics of the 92 elements.

Valence.—The members of each group of the periodic table have the same valence. Thus the members of Group 0 do not combine chemically, and have a valence of 0. Those of Groups I, II, III, and IV have a valence of 1, 2, 3, and 4, respectively. The elements of Group V have a valence of 3 when they combine with metals, and of 3 or 5 when they combine with oxygen. The members of Group VI have a valence of 2 when they combine with metals, and of 4 or 6 when they combine with oxygen. The elements of Group VII have a valence of 1 when combining with metals, and of 1, 3, 5, or 7 when combining with oxygen. The elements of Group VIII have a valence of 2 or 3. Thus the valence of any element is indicated when the group of the periodic table to which it belongs is known.

Metals and Non-Metals.—Looking at the table as a whole we will next note that the elements in Groups I and II, and

most of Group III (left side of table) are metals. Those in Groups VI and VII (right side of table) are non-metals. In Groups IV and V (middle of table) there are some metals and some non-metals. In fact, certain members of Groups IV and V partake of the characteristics of both metals and non-metals; that is, they behave like metals under certain conditions and like non-metals under other conditions. Thus, in general, we may say that the metallic characteristics of the elements are exhibited by the members of the left side of the table and the non-metallic characteristics by the members of the right side of the table; and certain members of the middle groups of the table partake of the properties of both metals and non-metals.

Discovery of New Elements.—The periodic table has pointed the way to the discovery of new elements. When Mendeléeff first arranged the elements in a periodic table there were a number of gaps, or vacant spaces, in the latter. He rightly claimed that these gaps represented places for undiscovered elements, and actually predicted from a knowledge of the periodic table what the properties of these elements would be. Mendeléeff's announcement was the stimulus for the research which finally brought about the discovery of certain unknown elements. Now all the places in the periodic table have been filled.

How Many Elements?—The periodic table offers an answer to the question: How many elements are there in the materials of the earth? The periodic table has 92 places in it, all of which have been filled. Of course, there might be elements of greater mass than that of the heaviest known element, which is uranium. We know, however, that elements heavier than uranium would very probably be unstable, and hence would be undergoing decomposition and giving indications of their existence, as uranium does. We have no evidence of matter that behaves in such a manner other than several elements lighter than uranium, which are well known. Elements heavier than uranium might have existed in the earth at an earlier period of its history. But

the lack of stability of such elements would very probably have resulted in their disintegration and disappearance from the earth millions of years ago.

Questions for Study

1. What is the periodic law of the elements as expressed by Mendeléeff?
2. Show how the periodic table was developed.
3. What are atomic numbers?
4. Mention an experimental demonstration to justify the use of atomic numbers.
5. State the periodic law in its modern form.
6. Show how the elements of the periodic table are arranged in groups of natural families.
7. What valence relationships are indicated by the periodic table?
8. How are the elements in the periodic table grouped with respect to metals and non-metals?
9. In what way has the periodic table led to the discovery of new elements?
10. How do we know that there are probably only 92 elements?

CHAPTER V

THE STRUCTURE OF MATTER

Introduction.—Up to this point in our text we have proceeded upon the hypothesis that the fundamental units of matter are atoms, and have not suggested to the student that the atoms are divisible. It now becomes important to introduce this point of view and to consider what is the nature of the atom. A great amount of research has been done along this line and, as a result of this research, we are now in possession of information that is very helpful in explaining the phenomena of chemistry, and is very stimulating to the student who likes to know the nature of things. The atoms of the elements, the "bricks" of matter, are made of smaller units, which are called electrons, protons, and neutrons.

Electrons.—The electron is the atom of negative electricity. Just as we have considered the atom of the elements as a basic unit of matter, so we may think of the electron as the fundamental unit of negative electricity. The electron is exceedingly small. It is 1,845 times lighter than the hydrogen atom. On the scale of atomic weights, where oxygen weighs 16, the electron has a relative mass of 0.00054. The electron exists in the outer portions of the atom. It is the particle which conveys a current of electricity along a wire or through a battery. Electrons are emitted from the cathode of an x-ray tube, from radio tubes, and from several of the heavier elements, the so-called radioactive elements. Thus the physical existence of electrons is observable and may be readily demonstrated.

Protons.—The proton is the atom of positive electricity. It exists in the nuclei of the atoms of the elements. The nucleus of the hydrogen atom consists of one proton. The proton is about 1,800 times heavier than the electron. On the scale of atomic weights (O = 16) the relative mass of the proton is 1.0072, which is approximately equal to that of the neutral hydrogen atom.

Free protons are liberated when neutral hydrogen atoms are stripped of their electrons by the passage of an electric discharge through hydrogen gas at a low pressure in a vacuum tube. Protons may thus be separated from the atoms of matter and their properties studied.

Neutrons.—A neutron is a particle of matter which has the same mass as the proton, but it does not bear an electrical charge. The neutron exists in the nucleus of the atom. Neutrons were first demonstrated to be present in matter by exposing beryllium or boron to the very penetrating rays emitted by polonium, a radioactive element. In such experiments neutrons are ejected from the nuclei of the beryllium or boron atoms. The existence of neutrons was discovered in 1932 by Chadwick at Cambridge, England.

Structure of the Atom.—The atom is composed of protons, neutrons, and electrons.* It consists of two distinct parts—a *nucleus made up of protons and neutrons, and a series of outer shells in which there are electrons only.* The electrons in the outer shell move around the nucleus in definite orbits, and because of the resemblance of their motion around the nucleus to the movements of the planets around the sun they are called planetary electrons.

The atom is exceedingly small, yet its relative size in comparison with the size of its constituent parts, the protons, neutrons, and electrons, is really enormous. As very aptly described by one author:[1] "The atom, therefore, is mainly void, a thing of specks and spaces—mainly spaces."

The mass of an atom is determined almost wholly by its protons and neutrons which are about 1,800 times heavier than electrons. The mass of the atom, therefore, resides principally in the nucleus which contains all of the protons and

*Another particle of matter, the positron, was discovered in 1932 by Anderson at the California Institute of Technology. A positron is a positive electron. It has the same mass as the negative electron, but bears an electrical charge of the opposite sign. The evidence indicates that the positron does not pre-exist in the atom and is formed by the bombardment of the nucleus of the atom by fast-moving particles of great energy. The positron is thus formed at the time it is emitted, it is believed, by a conversion of energy into matter. Since it apparently does not exist pre-formed in the atom, it will not receive consideration in this discussion of the structure of the atom.

[1]Findlay, A.: The Spirit of Chemistry, p. 86.

neutrons. The chemical properties of an atom are determined by the number and arrangement of the electrons in its outermost orbit.

When an atom enters into a chemical reaction its nucleus does not undergo any change, hence an atom preserves its mass (atomic weight) in all chemical reactions. The only changes that occur in atoms entering into chemical reactions are those in which electrons are lost from, or added to, the outermost orbits. Such changes do not alter much the architecture of the atom. But, as we shall see later, they bring about the great variety of changes in matter which we designate as chemical changes.

The fundamental differences in the atoms of the 92 elements are due to a variation in the number of protons, neutrons, and electrons of which the atoms are composed.

Examples of Atomic Structures.—The underlying postulates regarding the structure of the atoms of the different elements may be summarized as follows:

1. The number of protons in the nucleus of an atom is equal to the atomic number.

2. The number of neutrons in the nucleus of an atom is equal to the difference between its atomic weight and atomic number.

3. The number of electrons in the orbits of a neutral atom is equal to the number of protons in the nucleus, or the atomic number.

Keeping these rules in mind, we may now proceed with some theoretical atom building by consulting our table of atomic weights and atomic numbers on the inside page of the front cover.

The atomic number of hydrogen is one and the atomic weight of this element is the same (1.0078). Hydrogen contains a single proton in its nucleus and one electron in an orbit surrounding the nucleus.

Helium has an atomic weight of 4 and an atomic number of 2. The number of protons in the nucleus of helium is the same as its atomic number, which is 2. The number of neu-

trons in the nucleus is equal to the difference between the atomic weight and atomic number, or 2. The number of planetary electrons is the same as the atomic number, or 2. Thus we have in helium an atom containing 2 protons and 2 neutrons in its nucleus and 2 electrons in a single orbit around the nucleus. The structure of helium is shown diagrammatically in Fig. 3.

Fig. 3.—Diagrams illustrating the atomic structure of the elements, hydrogen, helium, and lithium. P represents protons and N represents neutrons. The – signs indicate negative electrons. (The size of the nucleus is greatly exaggerated to enable the artist to indicate the constituents present. The drawings of the atom in this text merely indicate the constituents present and are not intended to suggest the relative sizes of the components or extent of spacings within the atom.)

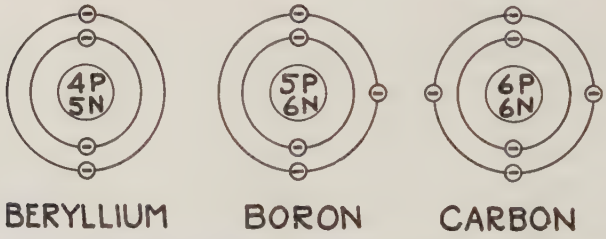


Fig. 4.—Diagrams illustrating the atomic structure of beryllium, boron, and carbon. P represents protons and N represents neutrons. The – signs indicate negative electrons.

Helium is an element which does not undergo chemical change. We, therefore, consider a structure like helium in which there are 2 electrons in the first orbit around the nucleus as a very stable structure. In the larger elements, where there are more than 2 electrons, the helium arrangement of 2 electrons in the first orbit is always maintained and the other electrons are in additional orbits surrounding the nucleus.

The atomic number of lithium is 3. Its nucleus, therefore, contains 3 protons. Lithium has an atomic weight of 6.94, or approximately 7; hence the number of neutrons in its nucleus is 7 minus 3, or 4. Since the atomic number is 3, the number of electrons is 3. Lithium is thus an atom consisting of a nucleus in which there are 3 protons and 4 neutrons, and an outer portion in which there are 2 electrons in the first orbit and 1 electron in the second orbit. The structure of lithium is shown in Fig. 3.

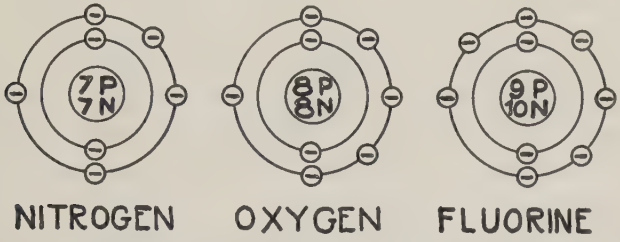


Fig. 5.—Diagrams illustrating the atomic structure of nitrogen, oxygen, and fluorine. P represents protons and N represents neutrons. The – signs indicate negative electrons.

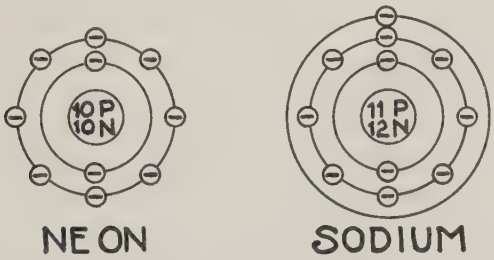


Fig. 6.—Diagrams illustrating the atomic structure of neon and sodium. P represents protons and N represents neutrons. The – signs indicate negative electrons.

Oxygen has an atomic number of 8 and an atomic weight of 16. The nucleus of the oxygen atom, therefore, contains 8 protons and 16 minus 8, or 8 neutrons. As the number of electrons in a neutral atom is equal to the number of protons in the nucleus, there are 8 electrons in the outer portion of the oxygen atom, 2 being in the first orbit and 6 in the second orbit. The structure of oxygen is shown in Fig. 5.

We may thus develop the structure of the atoms of the other elements, but these examples will suffice to illustrate

the principles involved. The student should study carefully the diagrams of Figs. 3, 4, 5 and 6, showing the structure of the first 11 elements in the Periodic Table.

What Is a Chemical Change?—*Chemical reactions consist of changes involving either the transfer of electrons from one atom to another atom, or the sharing of electrons by two atoms.* An atom entering into a chemical reaction either takes from, or shares with, or gives to, another atom, one or more electrons. The chemical activity of an element is thus determined by the ability of its atoms to give up, or share, or gain electrons. This is dependent upon the number of electrons in the outer orbit of an atom and the distance of these electrons from the nucleus. *There is no change in the nucleus of the atom during ordinary chemical reactions, and the change in the atom that does occur always involves the electrons in the outermost orbit.*

Valence.—We have previously defined valence as the combining requirement of an element entering into a chemical reaction. We shall now consider the underlying causes of this characteristic of the elements. The modern explanation of valence is based upon a consideration of the electrons in the *outermost orbit* of the atoms of elements. As shown previously, *each atom has a certain number of electrons in its outermost orbit. These electrons are called valence electrons.* In a chemical reaction the atoms either gain, lose, or share, valence electrons. If an atom gives up, let us say, 1 valence electron in a chemical reaction, its valence is 1, and it is positive because it has lost a negative particle; if an atom takes up 1 valence electron in a chemical reaction, its valence is 1, and it is negative because it has gained a negative particle. Similarly, if an atom gains or loses 2, 3, 4, or 5 valence electrons, its valence is 2, 3, 4, or 5, respectively, and it is positive if electrons are lost, or negative if electrons are gained.

To illustrate, let us take the elements lithium and oxygen. Lithium is an element which loses one valence electron in its chemical reactions; therefore, the valence of lithium is 1, and it reacts as a positive element because it loses a

negative particle. When oxygen enters into chemical reactions it requires 2 valence electrons to fill out its outer orbit; it gets these electrons by sharing or taking 2 electrons from the element with which it reacts. Oxygen, therefore, has a valence of 2, and reacts as a negative element because it gains negative particles.

Why Chemical Changes Occur.—We have briefly outlined above *what* takes place when a chemical reaction occurs. It now becomes important to consider *why* these changes occur. *Chemical reactions are the result of the tendency of matter to reach a more stable state under the existing conditions.* Of the 92 elements there are 6 that do not enter into chemical reactions, which means that they do not gain or lose electrons, and thus have a valence of zero. These elements are helium, neon, argon, krypton, xenon, and radon. Since these elements do not enter into chemical reactions, we are led to think that the arrangement of the electrons in their outermost orbits must be a stable one. *It is, therefore, a reasonable hypothesis to assume that chemical reactions are changes whereby the outermost orbits of the elements that do enter into chemical changes are rearranged to become like the outermost orbits of those elements that do not enter into chemical changes. This means that chemical reactions are changes whereby the outermost orbits of the atoms of reacting elements are changed to become like the outermost orbits of either helium, neon, argon, krypton, xenon, or radon.* Just which one of these 6 elements the reacting element will attempt to become like in its outer orbit is determined by the nearness of the reacting element to the nonreacting one in structure and atomic number. Obviously, the change that will take place will be the easiest one to produce mechanically, hence *a reacting element will always assume an outer arrangement of its electrons like that of one of the two stable elements that is nearest to it in atomic number.*

To make its outermost orbit like that of one of the six stable elements, an element may either (1) take up electrons from another element, or (2) give up electrons to another

element, or (3) share electrons with other elements. To make our discussion clear we shall now consider the chemical reactions of some of the simplest elements.

Chemical Changes of a Group of the Simplest Elements. —In the following discussion the student should refer to Fig. 7 on page 75 repeatedly. Upon examination of this diagram it will be seen that there are 2 electrons in the single orbit of helium; and 2 electrons in the first orbit and 8 electrons in the second, or outer, orbit of neon. To begin our discussion we must repeat that helium and neon are stable elements; an atomic structure in which there are 2 electrons in the first orbit, like helium, or 2 electrons in the first orbit and 8 in the second orbit, like neon, is a stable arrangement; and chemical reactions of elements near helium or neon in atomic number involve changes in the arrangement of their outer orbits that will produce an orbital arrangement either like that of helium or like that of neon.

The hydrogen atom contains 1 proton in its nucleus and a single electron in its orbit. This is not a stable arrangement; consequently atoms of hydrogen have a strong tendency to combine with each other. In combining, 2 hydrogen atoms unite to form a molecule by bringing their nuclei together near a common center and holding each of their electrons in an outer orbit like that of helium. Hydrogen also enters into chemical reactions where its single electron is introduced into the orbit of another element, and is at the same time held by hydrogen itself. This process is called sharing of electrons. In this manner hydrogen helps to fill out the orbits of other elements and make the latter stable, and at the same time is apparently stabilized itself. Hydrogen has a valence of 1. This is because the hydrogen atom has 1 electron to enter into chemical reactions.

Lithium has 2 electrons in its first orbit and 1 electron in its second, or outer, orbit. In order to become stable, lithium may lose 1 electron from its outer orbit and have an arrangement like helium (see Fig. 7). The only other possibility for lithium to assume a stable form is to fill out its second orbit by taking on 7 electrons and thus become

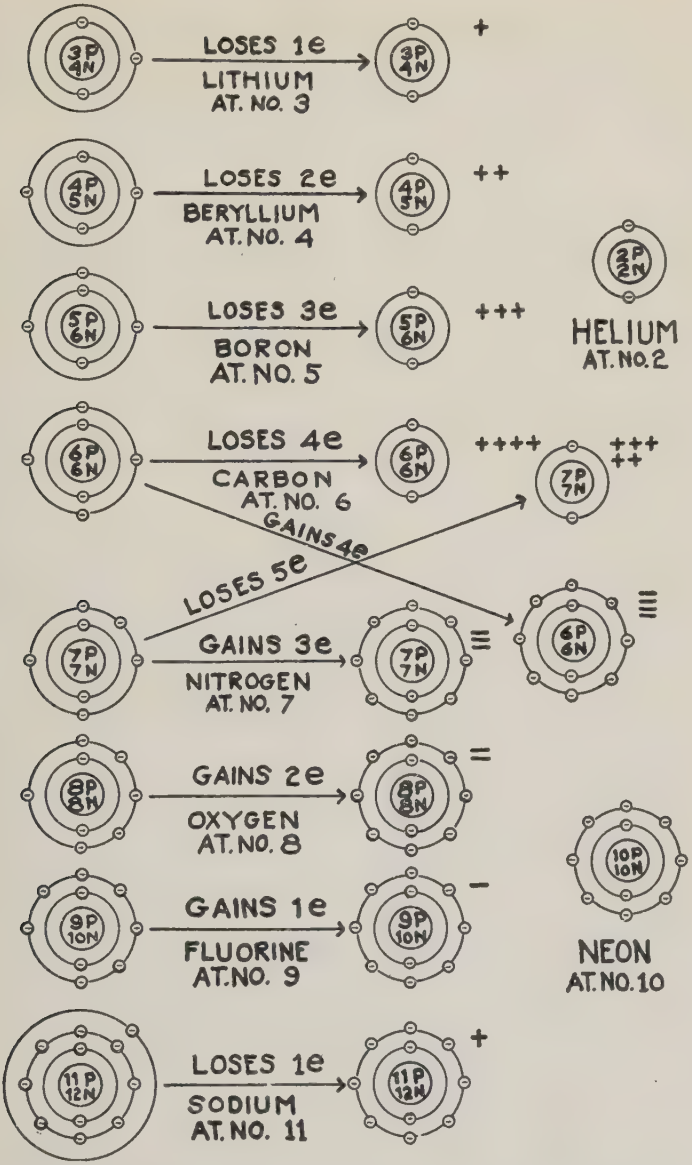


Fig. 7.—Diagram showing changes in 8 of the simplest elements when they enter into chemical reactions. Helium and neon are inactive. When entering into chemical reactions, lithium, beryllium, and boron assume the outer form of helium; oxygen, fluorine, and sodium assume the outer form of neon; carbon and nitrogen may assume the outer form of either helium or neon. In all cases the nuclei of the atoms remain unchanged.

like neon in its outer configuration. This is obviously very difficult and does not occur. Hence lithium enters only into chemical reactions where it gives up the 1 electron of its second orbit to some element that needs an electron to make it stable, and in doing this, lithium manifests a positive valence of 1.

Beryllium has 2 electrons in its second, or outer, orbit. The simplest procedure for beryllium to become stable is to lose 2 electrons from its second orbit and have an outer orbit like that of helium. This is what beryllium does when it enters into chemical reactions (see Fig. 7). The valence of beryllium is therefore 2, since it gives up 2 electrons in its chemical reactions. From this it is clear that beryllium is always positive in its chemical reactions because it loses electrons.

Boron has 3 electrons in its second, or outer, orbit. When entering into chemical reactions this element gives up the 3 electrons in its second orbit, but keeps unchanged its first orbit, which contains 2 electrons, thereby assuming an outer form like that of helium (see Fig. 7). Recalling again that helium is a stable element, it is clear that this change gives boron stability. Since boron loses 3 electrons in its chemical reactions, it has a valence of 3 and behaves as a positive atom.

Carbon has 4 electrons in its second, or outer, orbit. For carbon there are two possible changes in the arrangement of the electrons of its outer orbit when it enters into chemical reactions. This element can lose the 4 electrons of its second orbit and have an outer arrangement like that of helium; or it can take into its second orbit 4 electrons and have an outer configuration like that of neon. Either of these changes gives carbon stability, and both of them occur (see Fig. 7). The valence of carbon is, therefore, always 4. If it loses 4 electrons, it has a positive valence of 4; if it gains 4 electrons, it has a negative valence of 4.

Nitrogen has 5 electrons in its second, or outer, orbit. To become stable this element may lose the 5 electrons of its second orbit and have an outer orbit like that of helium, or it may add 3 electrons to its second orbit and have an outer

structure like neon. Nitrogen enters into chemical reactions involving both of these changes (see Fig. 7). When it loses 5 electrons, it has a positive valence of 5; when it gains 3 electrons, it exhibits a negative valence of 3.

From the above discussion of nitrogen and carbon it should become clear to the student why some elements have more than one valence. Certain elements, like these two, occupy a position about midway between two stable elements, so that it is possible for them to assume an outer electron arrangement like that of either of the near-by stable elements.

Oxygen has 6 electrons in its outer orbit. To assume a stable configuration oxygen must either lose the 6 electrons of its outer orbit and have an outer arrangement like that of helium, or it must add 2 electrons to its outer orbit and assume an outer form like neon. The latter process would seem to be the easier to accomplish, and actually this is the only one that does occur. In all of its chemical reactions oxygen enters only into processes whereby it gains 2 electrons, making its outer orbit like that of neon (see Fig. 7). Oxygen, therefore, has a negative valence of 2, since it gains 2 electrons in its chemical reactions.

Fluorine has 7 electrons in its outer orbit. The simplest procedure for fluorine to become stable is to add 1 electron to its outer orbit, becoming like neon in the arrangement of its outer electrons (see Fig. 7). This is what fluorine does in its chemical reactions. Fluorine, therefore, has a negative valence of 1.

Sodium, the last element we shall discuss, has 2 electrons in its first orbit, 8 electrons in its second orbit, and 1 electron in its third, or outer, orbit. In chemical reactions this element assumes a more stable form by losing the one electron of its third orbit and becoming like neon in its first and second orbits. The only other possibility of sodium assuming the outer form of one of the stable elements is to add 7 electrons to its third orbit and have an outer electron arrangement like argon, the next stable element nearest to sodium in atomic number. Such a change is quite difficult and does not occur. Sodium thus enters only into chemical

changes whereby it loses the one electron of its third orbit which gives it an outer arrangement like that of neon (see Fig. 7). Sodium, therefore, has a positive valence of 1.

Most of the foregoing reactions involve a *transfer of electrons* from one atom to another. Another type of reaction remains to be discussed more fully. This type is where there is not an actual transfer of electrons, but *a sharing of electrons by atoms.* By sharing of electrons we mean atoms come very close together and hold in common pairs of valence electrons in their outer orbits. In sharing electrons many elements are able to fill out the outermost orbits of their atoms, and thus form stable combinations in the same manner as other elements accomplish this by a complete transfer of electrons. *The same principles of approaching the outer form of the nearest stable element, as outlined above for the transfer of electrons, hold good for the reactions which involve the sharing process.* This will be made clearer by Fig. 9.

From what has been said, it is obvious that all chemical reactions come under two types. These involve either (1) a transfer of electrons, or (2) a sharing of electrons. To make our previous discussion clearer we will now give an example of each type:

1. *Reaction between lithium and fluorine—a transfer of electrons.* Lithium has 1 electron in its outer orbit. It must lose this electron and have an outer structure like helium to become stable. Fluorine has 7 electrons in its outer orbit. To have a stable arrangement, fluorine must gain 1 electron and have an outer structure like neon. Stating the situation briefly, the lithium atom must lose 1 electron to react chemically, and the fluorine atom must gain 1 electron to do the same. The outcome of this situation is obvious. The lithium atom gives up an electron to the fluorine atom, and the two atoms are thus combined chemically, forming a molecule of lithium fluoride. This chemical reaction is illustrated by Fig. 8.

2. *Combination of fluorine atoms—a sharing of electrons.* As we noted above, fluorine has 7 electrons in its outer orbit. To become stable it fills out its outer orbit by taking

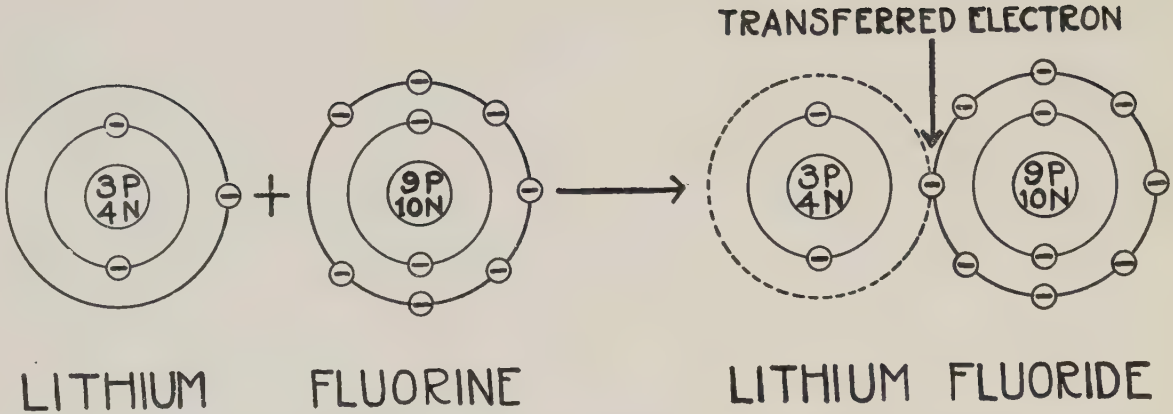


Fig. 8.—Diagram showing chemical reaction between lithium and fluorine, a case of transferring of electrons.

up 1 electron, becoming like neon in its outer structure. Fluorine is a very active element and will readily seize electrons from other atoms which have them to offer. But when fluorine atoms are liberated alone, they combine with each other. Obviously in combining there can be no transfer of electrons since the fluorine atoms all require electrons to fill out their orbits. To explain this we assume that two fluorine atoms share a pair of electrons in their outer orbits. By a sharing process the outer orbit of each fluorine atom is made to contain 8 electrons, which satisfies its reacting requirement, and the result is the formation of a stable fluorine molecule. This process is illustrated by Fig. 9.

Summary of Valence and Chemical Change.—The elements here discussed are sufficient to indicate the nature of valence and chemical change. The valence of an element is determined by the number of electrons it must gain, lose, or share, in order to reach a stable arrangement of its outer electrons. The change in the valence electrons that occurs is determined by the nearness of the element in structure to one of the six stable elements. Elements that are near a stable element will assume the outer form of the stable element by gaining, losing, or sharing, valence electrons. Elements about midway between two of the stable elements may assume the outer form of either of the two stable elements by gaining or losing electrons and thus have two valences. The principles outlined above for nine of the simplest elements apply the same to the rest of the elements. *All chemical reactions are changes in which the reacting elements assume the outer arrangement of the electrons of either helium, neon, argon, xenon, krypton, or radon, the six elements which have been found to be very stable.*

Isotopes.—For a long time it was thought that the atoms of elements were fixed units of matter of unvarying composition and identical physical and chemical characteristics. Experimental observations gradually accumulated, however, showing that there are different forms of the same element among the naturally occurring elements, and recently methods have been developed (see section on artificial radioac-

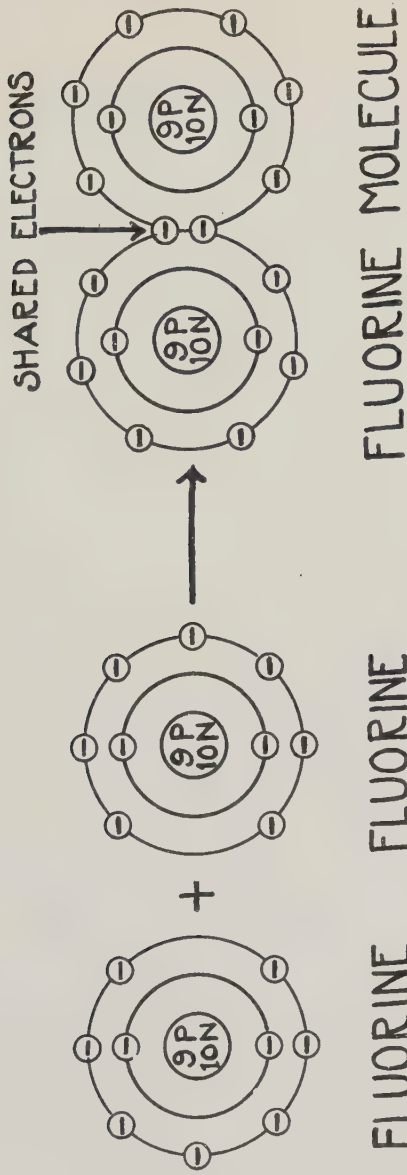


Fig. 9.—Diagram showing combination of fluorine atoms, a case of sharing of electrons.

tivity, page 185) by which elements may be changed into other forms. The variable forms of the same elements are called isotopes.

In isotopes the variation in structure is in the nucleus of the atom; there is the same number of protons, but a difference in the number of neutrons. This difference in the number of neutrons gives the element a different mass; hence isotopes vary in atomic weight. Since the number of protons in the nucleus is the same, the atomic number of isotopes is the same. There is no difference in the number or arrangement of the electrons of isotopes. This means that isotopes have the same kind of chemical properties, although the intensity or rate of chemical reactions will vary slightly, because the atoms of the heavier isotopes, having a greater mass, will be more sluggish in their reactions.

It is important to stress the fact that isotopes have the same atomic number. Elements may, therefore, be more accurately defined here than in our previous discussion (page 34): *An element is a fundamental form of matter consisting of atoms having the same atomic number.*

To illustrate, let us take the element chlorine as an example. In the table of atomic weights, this element has an atomic number of 17 and an atomic weight of 35.45. There are two isotopes of chlorine: one has an atomic weight of 35, and the other, 37. Actually, the atomic weight of 35.45 is an average value which chemists have obtained in analyses of chlorine as it occurs in nature, which consists of a mixture of the isotope weighing 35 and the one weighing 37. The isotope weighing 35 consists of 17 protons, 17 electrons, and 18 neutrons; the one weighing 37 consists of 17 protons, 17 electrons, and 20 neutrons. Thus chlorine is an element existing in two forms having different masses but essentially the same chemical properties; the difference in the masses of the two isotopes is due to the different number of neutrons in the nucleus.

Recent discoveries have shown that there are at least two isotopes of hydrogen. One of these isotopes is the ordinary form of hydrogen which has an atomic weight of 1 and

exists in Nature in great abundance. This is the form that is meant when hydrogen is referred to elsewhere in this text. The other isotope of hydrogen has an atomic weight of 2 and is found in Nature in a ratio of 1 part to 5,000 parts of the more abundantly occurring usual form. This form of hydrogen has been given the name deuterium. It is commonly called "heavy hydrogen." Structurally, the nucleus of the deuterium atom contains one proton and one neutron, and in the outer portion of this atom there is one electron.

The existence of elements in the form of isotopes is the rule of Nature rather than the exception. Most of the 92 elements exist in the form of isotopes, and some show a considerable number of isotopic forms. The isotopes of a few of the elements are shown in Table III, page 84.

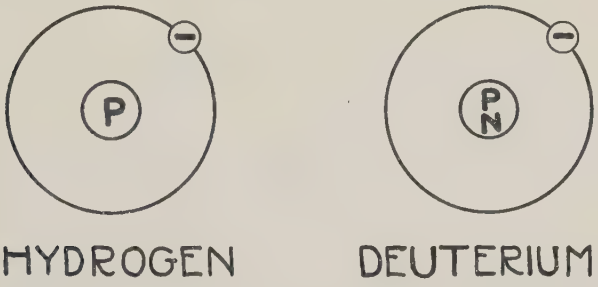


Fig. 10.—Diagram showing the differences in the structure of hydrogen and deuterium. P represents protons and N represents neutrons. The − signs indicate negative electrons.

From the foregoing it probably has already occurred to the student that *atomic weights are really average values. Most of the atomic weights shown in the table on the front cover are the relative weights of mixtures of isotopes in the proportions that naturally occur in the matter of the earth.*

An application of isotopes of great interest in biochemistry is their use in studying the changes that take place in living things. Isotopes may be introduced into compounds to serve as labels. Such compounds may then be fed to an animal or introduced into the tissues of a plant. These compounds, being labeled by the presence of isotopes in their molecules, may then be traced by the investigator through an animal's body or in the tissues of a plant. The use of

isotopes for labeling compounds of interest in the metabolism of animals and plants has already assumed great importance and offers great possibilities in the future.

TABLE III

ISOTOPES OF SOME ELEMENTS

ELEMENT	ATOMIC WEIGHT OF USUAL FORM	ATOMIC WEIGHT OF ISOTOPES
Hydrogen	1.0078	2
Oxygen	16.00	17, 18
Magnesium	24.32	24, 25, 26
Chlorine	35.45	35, 37
Potassium	39.10	39, 41
Iron	55.84	54, 56
Silver	107.88	107, 109
Tin	118.70	116, 117, 118, 119, 120

Questions for Study

1. What is an electron? What is the unit that carries an electric current?
2. What is a proton? A neutron?
3. Describe the structure of the atom.
4. What value of the atom corresponds to the number of protons in the nucleus?
5. How is the number of neutrons in the nucleus of the atom ascertained?
6. What atomic value corresponds to the number of electrons in the orbits of an atom?
7. How many protons are in the nucleus of an atom of calcium? How many neutrons? How many electrons are in the orbits of the calcium atom?
8. What changes in atoms occur when they take part in chemical reactions?
9. What is a valence electron? Give an explanation of valence in terms of electrons.
10. What atoms do not enter into chemical changes? Why?
11. Describe what changes occur when the following atoms enter into chemical reactions: lithium; carbon; oxygen; sodium.
12. Explain why nitrogen has a valence of 3 and of 5.
13. Distinguish between transfer and sharing of electrons.
14. Give a summary of valence and chemical change in terms of electrons.
15. What are isotopes?
16. What is deuterium?
17. Give an exact definition of the element.
18. What is the importance of isotopes?

UNIT III

HYDROGEN AND OXYGEN: PROPERTIES, USES AND SOME IMPORTANT COMPOUNDS

CHAPTER VI

HYDROGEN

Occurrence.—Hydrogen is a widely occurring element. It constitutes about 1 per cent of the mass of the earth's crust, but it has a much greater importance than is indicated by this percentage. The name "hydrogen" is derived from a Greek word meaning "producer of water," and it was so named because it forms water when it combines with oxygen. Hydrogen exists as the free element in traces in the air, in the gases of volcanic eruptions, and in the gaseous mantles surrounding the sun and the hotter stars. The chief occurrence of hydrogen, however, is in the combined state. Combined with other elements, it is found in water, acids, alkalies, plant and animal tissues, natural gases, and many other substances.

Preparation.—As one would naturally expect, hydrogen is prepared by releasing it from some of the compounds in which it occurs. Of these compounds it is most readily obtained from acids and from water. We shall describe the simpler methods of preparation from these two sources.

1. *The reaction of acids with certain metals,* for example, zinc with hydrochloric acid, produces hydrogen.

$$\underset{\text{Zinc}}{Zn} + \underset{\text{Hydrochloric acid}}{2\,HCl} \rightarrow \underset{\text{Zinc chloride}}{ZnCl_2} + \underset{\text{Hydrogen}}{H_2}$$

In the above equation, zinc chloride is formed, zinc having a greater affinity for chlorine than hydrogen, and hydrogen passes off as a gas, which is collected by displacement of water, as shown in Fig. 11.

Hydrogen may be prepared from many acids, but hydrochloric and sulfuric acids are the most convenient and the

most satisfactory. A number of other metals, such as iron, tin, nickel, calcium, magnesium, may be used instead of zinc in the preparation of hydrogen by this method, but there are certain metals, namely, copper, mercury, silver, gold, platinum, which will not react with acids and liberate hydrogen. The action of metals upon acids is a convenient method of preparing hydrogen and is the one used in laboratory work.

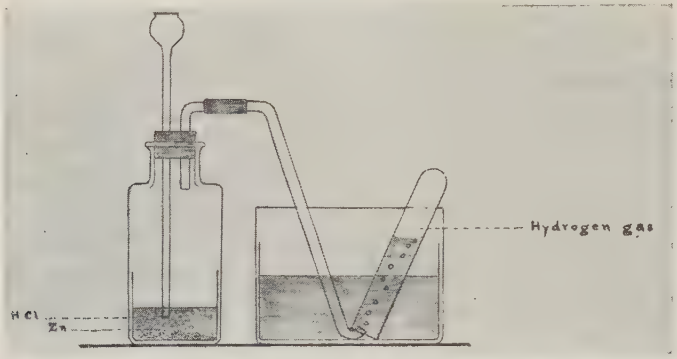


Fig. 11.—Preparation of hydrogen, using zinc and hydrochloric acid.

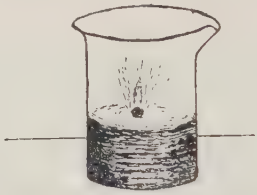


Fig. 12.—Reaction of potassium with water.

2. *The reaction of certain metals with water.* If a small piece of potassium is tossed upon water, hydrogen is evolved; the heat of the reaction is so great that the hydrogen is ignited and burns as it leaves the surface of the water (Fig. 12).

2 HOH	+	2 K	→	2 KOH	+	H_2
Water		Potassium		Potassium hydroxide		Hydrogen

In this reaction one atom of hydrogen is removed from each water molecule and the other hydrogen atom remains attached to the oxygen; the oxygen atom and its attached

hydrogen atom combine with an atom of potassium, forming potassium hydroxide, a compound we will study later. The released hydrogen atoms combine in pairs, forming molecules of hydrogen (H_2), and the hydrogen molecules, being very light, pass off as a gas.

Water is also decomposed by the metal sodium, hydrogen being liberated.

$$\underset{\text{Water}}{2\ HOH} + \underset{\text{Sodium}}{2\ Na} \rightarrow \underset{\text{Sodium hydroxide}}{2\ NaOH} + \underset{\text{Hydrogen}}{H_2}$$

This reaction is entirely similar to that given by potassium and water, except that less heat is evolved. The hydrogen liberated is not ignited by the heat of the reaction, but may be burned by applying a lighted match.

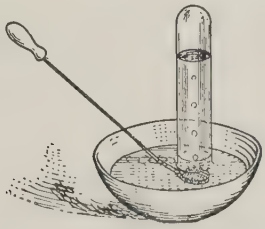


Fig. 13.—Preparing hydrogen from water. (From Peter's *Chemistry for Nurses.*)

To demonstrate that hydrogen is the gas evolved by these metals, place a small piece of sodium in a gauze spoon, and plunge it very quickly under an inverted test tube of water in a vessel of water, as shown in Fig. 13. The water in the test tube will be displaced by the gas produced, and this gas can be identified as hydrogen by the tests given under properties of hydrogen.

Calcium and magnesium will decompose water and liberate hydrogen, but very much slower than potassium and sodium. Other metals, such as zinc, iron, copper, when heated to high temperatures, will react with water and liberate hydrogen.

Physical Properties.—Pure hydrogen is colorless and odorless. It is the lightest of all the elements, its atomic

weight being 1.0078. It is a gas at ordinary temperatures. By the application of considerable pressure and very low temperatures, hydrogen may be liquefied and even solidified. Solid hydrogen passes into the liquid state at –257° C.; liquid hydrogen becomes a gas at temperatures warmer than –253° C.

Hydrogen is very slightly soluble in water, 100 c.c. of water dissolving 2 c.c. of hydrogen gas at standard conditions of temperature and pressure. For practical purposes, hydrogen may be considered insoluble in water, and we take advantage of its low solubility in its preparation by collecting it by displacement of water in a jar inverted in a vessel of water.

Chemical Properties.—Hydrogen is not very active at ordinary temperatures, but at higher temperatures it combines with most non-metallic elements and with some metals. It burns readily, producing a nonluminous flame, but it does not support combustion. A burning splinter will be extinguished if placed in a jar of pure hydrogen. When hydrogen is burned in the presence of sufficient oxygen, the hottest flame known is produced. The hydrogen flame produced with an oxyhydrogen blowpipe yields a temperature as high as 2,500° Centigrade. Such a flame will vaporize gold and silver, and will melt platinum and asbestos. Hydrogen combines with oxygen at high temperatures with explosive violence. It is this familiar "pop," obtained when igniting a test tube of hydrogen mixed with air, that the student uses as a test for hydrogen in the laboratory.

The product obtained by burning hydrogen in oxygen, or air, is water. This can be demonstrated by collecting hydrogen in a dry test tube, and then igniting the mixture. After the ignition, water will be plainly visible on the sides of the test tube.

Hydrogen also has the very important property of removing oxygen from the oxides of certain metals at high temperatures. For example, if we pass hydrogen over copper oxide heated to redness, the oxygen is removed from its combination with copper and unites with the hydrogen.

Water will appear on the cool portions of the tube, and the black copper oxide will be changed into reddish metallic copper.

$$\underset{\text{Copper oxide}}{CuO} + \underset{\text{Hydrogen}}{H_2} \rightarrow \underset{\text{Copper}}{Cu} + \underset{\text{Water}}{H_2O}$$

Uses.—Hydrogen, being the lightest gas, was once used extensively for inflating balloons. Since the lifting power of a balloon is proportional to the difference between the weight of the gas used for its inflation and the weight of an equal volume of air, it follows that hydrogen has the greatest lifting power of all gases. But during World War I, and for several years thereafter, serious accidents occurred with hydrogen-filled balloons, which were due to the ignition of hydrogen and its explosive violence when burning. On account of the danger from combustion, the use of hydrogen has been largely discontinued, and helium, a gas that will not burn, has been substituted for hydrogen in the construction of balloons, more especially of the dirigible type.

Another important use of hydrogen is in the oxyhydrogen blowpipe. This apparatus, shown in Fig. 14, is a device for burning hydrogen in a regulated supply of oxygen. It consists of two pipes, one containing hydrogen, the other oxygen, which are so constructed that the gases can be delivered from their tips in proper proportions to produce the hottest flame obtainable from hydrogen when ignited. The temperatures obtained with the oxyhydrogen blowpipe range from 1,600° to 2,500° Centigrade, varying according to the proportion of hydrogen to oxygen in the mixed gases. With this apparatus a steel beam can be easily cut in two, and the welding of iron can be carried out readily. The oxyhydrogen blowpipe is thus a valuable piece of apparatus to workmen in the welding of steel parts in place, or to wrecking crews in tearing down structures made of thick steel beams.

The greatest commercial use of hydrogen at the present time is in the hardening of liquid fats. Many vegetable fats are unpalatable liquids and as such are unfit for human consumption. These "soft" fats, or oils, can be hardened

by treating them with hydrogen in the presence of finely divided nickel. For example, cottonseed oil is an ill-smelling liquid that is undesirable as a food, but by various steps of purification and a final treatment with hydrogen, it is converted into an excellent fat for cooking purposes. Crisco is an example of a purified and hydrogenated cottonseed oil product of considerable commercial importance. In addition to the preparation of solid fats for consumption

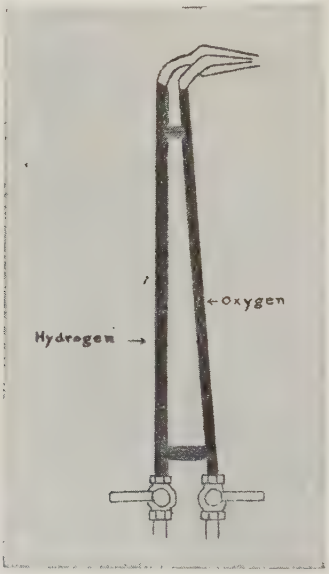


Fig. 14.—The oxyhydrogen blowpipe.

as foods, the hydrogenation of oils has been extended to the hardening of certain oils which are used in the manufacture of soaps.

Questions for Study

1. Where does hydrogen occur?
2. Describe two methods for the preparation of hydrogen.
3. Give three physical properties and three chemical properties of hydrogen.
4. What is formed when hydrogen burns in oxygen?
5. Give three uses of hydrogen.
6. Discuss the use of hydrogen in the preparation of Crisco

CHAPTER VII

OXYGEN AND OZONE

Oxygen

Occurrence.—Oxygen is the most abundant of all the elements. It exists both in the combined and in the free, or elementary, states. Combined with other elements, oxygen constitutes by weight one-half of the substances composing the earth's crust, eight-ninths of water, two-thirds of the human body and the body of animals, and one-half of the tissues of plants. As the free element, oxygen makes up about one-fifth of the air by volume, and is found in small quantities in the soil and dissolved in the natural waters of the earth. The abundance of oxygen as compared with other elements is shown graphically in Fig. 15.

Preparation.—

1. *From Mercuric Oxide.*—Perhaps the simplest method of preparing oxygen is by heating mercuric oxide. This is the method that was used by Priestley, who discovered this element in 1774. Priestley's method is represented by the following equation:

$$\underset{\text{Mercuric oxide}}{2\ HgO} + \text{heat} \rightarrow \underset{\text{Mercury}}{2\ Hg} + \underset{\text{Oxygen}}{O_2}$$

In this reaction the chemical attraction between mercury and oxygen is overcome by heating, and free mercury and oxygen are produced. The oxygen, being a gas that is only slightly soluble in water, is collected by displacement of water.

2. *From Potassium Chlorate.*—If we heat potassium chlorate, a compound containing oxygen, to about 400° Centigrade, oxygen will be liberated, and can be collected by displacement of water, as shown in Fig. 16. If we mix the potassium chlorate with a small amount of powdered manganese

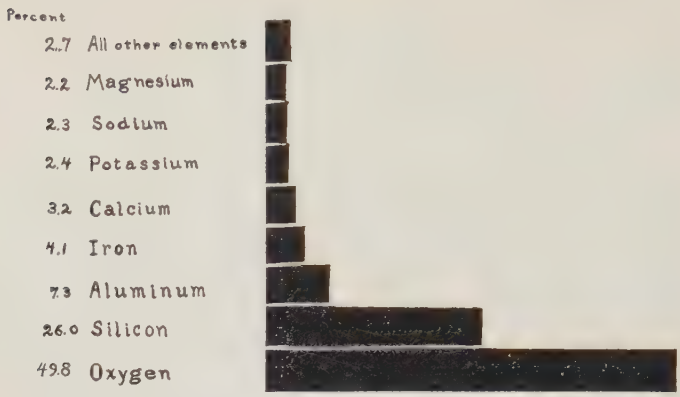


Fig. 15.—Graph showing relative abundance of the elements in the earth's crust.

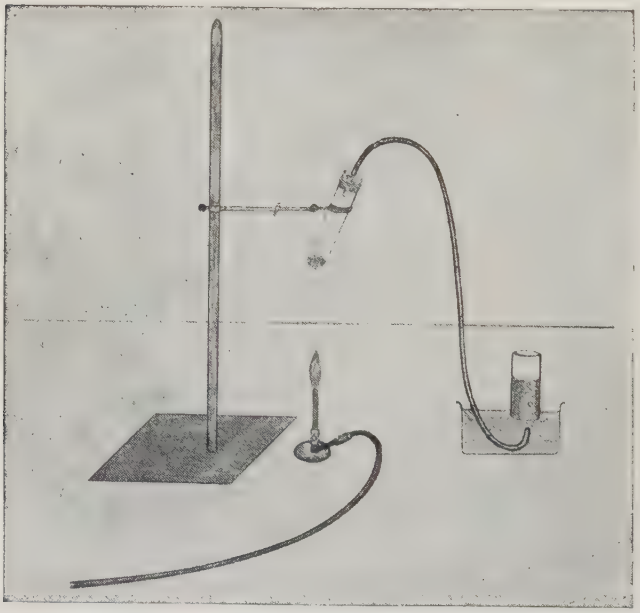


Fig. 16.—Preparation of oxygen by heating a mixture of potassium chlorate and manganese dioxide.

dioxide and heat the mixture, oxygen will be evolved at only half as high a temperature. The reactions are as follows:

1. $2\ KClO_3 + \text{heat (400° C.)} \rightarrow 2\ KCl + 3\ O_2$
   Potassium chlorate — Potassium chloride — Oxygen

2. $2\ KClO_3 + MnO_2 + \text{heat (200° C.)} \rightarrow 2\ KCl + 3\ O_2 + MnO_2$
   Potassium chlorate — Manganese dioxide — Potassium chloride — Oxygen — Manganese dioxide

In preparing oxygen according to the second equation, manganese dioxide is introduced because it stimulates the reaction and makes it possible to liberate oxygen at a much lower temperature (200° C.) than is necessary to prepare oxygen by heating potassium chlorate alone (400° C.) The manganese dioxide is not changed itself during the reaction, but in some manner its presence makes the chemical change take place more readily. *Substances which stimulate chemical reactions, as manganese dioxide accelerates the preparation of oxygen from potassium chlorate, are called catalysts. A catalyst is a substance which makes chemical reactions take place faster, or in some instances slower, without being changed itself.* We shall study catalysts again in the latter part of this book, more especially in connection with the reactions which take place in the human body.

3. *From the Air.*—Since the air consists chiefly of oxygen and nitrogen, the problem of preparing oxygen from air is the separation of these two gases. This separation can be accomplished by converting air into the liquid state, and then letting the liquid nitrogen evaporate away from the liquid oxygen. Air is liquefied by pumping it into strong chambers where it is submitted to great pressure at low temperatures. Later it is permitted to evaporate. Advantage is taken of the fact that liquid nitrogen evaporates at a temperature 13 degrees lower than that of liquid oxygen. The nitrogen, therefore, will escape first when liquid air is evaporated, and by this process a separation of the two gases is effected. Oxygen prepared in this manner is not pure, for it contains a small percentage of nitrogen and other gases of the atmosphere. Nevertheless, it is satisfactory for

commercial use, and is the method used at the present time to obtain oxygen for commercial purposes.

Physical Properties.—Oxygen is a colorless, odorless, tasteless gas. It is slightly heavier than air. One liter of oxygen weighs 1.43 grams, and one liter of air, under the same conditions of temperature and pressure, weighs 1.27 grams. It is slightly soluble in water, 100 c.c. of water dissolving 3 c.c. of oxygen at room temperature and a pressure of one atmosphere. Oxygen may be liquefied by applying great pressure to the gas at very low temperatures, and it may be converted into the solid state by applying pressure and producing still lower temperatures. Liquid oxygen is a bluish fluid which evaporates at −183° C. Solid oxygen is a pale blue snowlike substance with a melting point of −218° C.

Chemical Behavior.—

1. *Activity.*—Oxygen reacts with other substances slowly at ordinary temperatures and very vigorously at high temperatures. It is capable of combining with nearly all of the other elements and it will react with a great many compounds.

2. *Supporter of Combustion.—When substances enter into a chemical reaction which produces heat and light, the process is called combustion.* We commonly speak of this process as "burning." If a substance burns, it is said to be combustible. Examples of combustible materials are wood, ether, gasoline, hydrogen; these substances combine with oxygen at appropriate temperatures, and the chemical change produces heat and light. Since oxygen is essential for the combustion of so many substances, we consider oxygen a supporter of combustion rather than a combustible material. Other elements may take the place of oxygen in producing a combustion, but they are relatively unimportant in this respect. Combustion practically always means a chemical combination of some free element, or the elements of some compound, with oxygen at higher than ordinary temperatures. Oxygen is, therefore, *the great supporter of combustion.*

The influence of oxygen as a supporter of combustion can be easily demonstrated in the laboratory. If we thrust a feebly burning splinter of wood into a jar of pure oxygen, it will glow with a flame many times more brilliant than was exhibited in the air. Sulfur, which burns freely in the air, when ignited and placed in pure oxygen burns with a more brilliant flame. Iron, in the form of steel wool, will burn in pure oxygen with a dazzling flame, if it is heated to redness before placing it in the oxygen.

The necessity of oxygen for combustion is further demonstrated in the operation of a stove or furnace. If we shut off the "draught" and stop the admission of air, which is one-fifth oxygen, the fire will not burn. If we desire to increase the burning process, we open the air-regulating device and admit more air, which is equivalent to admitting more oxygen, and the fire burns more vigorously.

3. *Oxidation.—The union of oxygen with other substances is called oxidation. Reactions involving an increase in the positive valence of an element are also considered oxidations.* Oxidation may be slow or very rapid. When slow oxidation takes place, heat is evolved but is conducted away as rapidly as it is produced, and no increase in temperature is noted; the amount of heat liberated by the slow oxidation of a substance, however, is the same as that produced by the most rapid oxidation of a similar amount of the same substance. We see many instances of slow oxidation at ordinary temperatures in everyday life. The rusting of iron is a combination of iron with oxygen; the decay of plant tissues and of waste products of animals is an oxidation; the drying of paint is the union of oxygen with the linseed oil in which the paint is dissolved. At higher temperatures many substances can be oxidized which are not oxidized at ordinary temperatures. Oxidation also takes place more rapidly when the temperature is raised.

Oxidation is a very significant chemical change because of the heat that it liberates. It is by the oxidation of foods in the body that the energy stored in foods is made available for work and the body is kept warm. It is the oxidation of

wood and coal that produces the heat which warms our dwelling places and runs the engines of commerce and industry. Oxidation is, in short, a chemical reaction without which life would not exist.

A more fundamental discussion of the nature of oxidation will be given later in the chapter on oxidation and reduction. (Chapter VIII.)

Oxides.—*An oxide is a compound in which oxygen is combined with some other element or elements.* Oxides are usually formed by oxidation, or direct combination of oxygen with another element, as shown in the following equations:

1. $3\ Fe + 2\ O_2 \rightarrow Fe_3O_4$
   Iron — Oxygen — Iron oxide
2. $C + O_2 \rightarrow CO_2$
   Carbon — Oxygen — Carbon dioxide
3. $S + O_2 \rightarrow SO_2$
   Sulfur — Oxygen — Sulfur dioxide

Some oxides are prepared more conveniently by heating compounds containing several elements, of which oxygen is one. Thus

$$\underset{\text{Calcium carbonate}}{CaCO_3} + \text{heat} \rightarrow \underset{\text{Calcium oxide}}{CaO} + \underset{\text{Carbon dioxide}}{CO_2}$$

Spontaneous Combustion.—We have previously seen that oxidation of many substances takes place at ordinary temperatures. Sometimes such substances are packed in places where they oxidize slowly, and the heat produced is not removed, but accumulates until the temperature gets high enough to ignite the material. In this manner, fires are often started. Fires of such origin are said to be due to spontaneous combustion. *Spontaneous combustion is a self-starting combustion; it originates from the heat that accumulates in a confined region as a result of slow oxidation at ordinary temperatures.* Familiar examples of spontaneous combustion are those which occur in heaps of oily rags, especially rags containing linseed oil, which oxidizes readily; in coal yards where fine-grained soft coal is packed together in large

amounts; in factories where organic matter is piled too compactly; in "curing" hay upon the farm where green hay is packed in barns or large stacks.

Relation to Life.—Most living things require free molecular oxygen. This is because oxygen will unite with other substances and produce heat. Oxidation is thus a very important process in living things, for by the oxidation of foods heat is liberated and energy is made available for activity.

The oxygen requirements of plants are slight in comparison with animals, since plants are not mobile and do not require the same amount of energy as do animals. Plants also have the power of liberating free oxygen from carbon dioxide and water in the presence of sunlight, and they, therefore, do not have the same necessity of getting oxygen from the air that animals do.

Animals require large quantities of oxygen, and they must obtain it constantly and rapidly; without oxygen animal life would cease in a few minutes. Hence most animals have specialized organs (lungs, gills) for absorbing oxygen from the air or water and conveying it rapidly to their tissues. In the very lowest forms of animal life no special oxygen-absorbing mechanism is necessary, since these forms consist of relatively few cells, or of a single cell, and in these instances oxygen can be absorbed directly from the environment.

A few forms of life do not require free oxygen. Those forms which do not use free oxygen are called anaerobes, a name which means "without air." Certain bacteria, such as tetanus, botulinus, and anthrax, are examples of anaerobic organisms. These bacteria will not grow except in the absence of free oxygen.

The absorption of oxygen from the air and its conveyance to the tissues in the case of the human body are very interesting processes and are typical of all higher animals. When air is breathed into the lungs, oxygen passes through the thin layers of cells of the lung alveoli into the blood. The blood contains a protein, called hemoglobin, which com-

bines with oxygen, forming oxyhemoglobin. Hemoglobin is dark in color and oxyhemoglobin is bright red. For this reason, venous blood, which comes from the tissues and contains chiefly hemoglobin, appears dark in color, and arterial blood, which comes from the lungs and contains considerable oxyhemoglobin, has a bright red appearance. After the oxygen has combined with hemoglobin in the lung capillaries, the oxyhemoglobin formed is carried by the blood to the tissues. In the tissues oxygen is released from the oxyhemoglobin combination and used to oxidize, or "burn," food substances that have been carried to the tissues from the alimentary tract by the blood and lymph. The oxidation of foods in the tissues produces heat which is used to keep the body warm, and to provide energy for work and for the living processes of the body. Oxygen also oxidizes the worn-out tissues of the body and certain poisonous substances, and in this manner aids in the removal from the body of undesirable products, at the same time producing more heat and energy.

When foods are oxidized in the animal body, carbon dioxide, a colorless gas, is produced. This substance is undesirable in the body in excessive amounts, and is consequently carried by the blood to the lungs and excreted through the latter. Respiration then has a twofold purpose, taking oxygen into the lungs, where it can be absorbed by the blood and carried to the tissues, and removing carbon dioxide, an undesirable product, to the exterior.

From the above discussion it is evident that the constant withdrawal of oxygen from the air by animals would soon exhaust the oxygen content of the atmosphere, unless there is some process by which oxygen can be returned to the air. Furthermore, since animals are constantly giving off carbon dioxide, and a great deal of carbon dioxide is produced from burning wood and coal, some mechanism to prevent the accumulation of this substance is equally as important. Nature has provided well for this situation by the activities of plants. Plants absorb carbon dioxide from the air and water from the soil, and in the presence of sunlight

manufacture their own food. This process is called photosynthesis, a term meaning "put together by light." During photosynthesis oxygen is given off by the plant and in this way the oxygen supply of the atmosphere is continuously renewed. It is true that the plant uses some oxygen in its life processes, but by active photosynthesis a great deal more oxygen is produced than is necessary for the plant's needs, and the extra oxygen is given off by the plant into the atmosphere. Plants thus have a purifying influence upon the air; they remove carbon dioxide and supply free oxygen. As oxygen passes from the plant to the animal in the form of free oxygen, and back to the plant again in the form of carbon dioxide, the process is a complete cycle, and is commonly referred to as the *oxygen cycle in nature.*

Uses of Oxygen.—Oxygen is the most useful of all the elements. We will summarize its importance as follows:

1. *For Respiration.*—All plants and animals, except a few anaerobes, require free molecular oxygen for the living processes which take place in their tissues.

2. *Medical Uses.*—For short periods of administration, oxygen is given through a mask applied directly to the patient's nose and mouth. When it is desirable to administer pure oxygen for longer periods of time, the patient is placed in an oxygen tent. The following applications are of interest:

a. *In pneumonia.* The administration of pure oxygen is an important aid in the treatment of pneumonia. When a patient is suffering from pneumonia, a considerable portion of the breathing surface of the lungs is not functioning. If the condition is severe, it is advantageous to place an oxygen tent over the patient so that pure oxygen may be breathed instead of air which contains only 20 per cent of oxygen. Placing the patient in an atmosphere of pure oxygen promotes the intake of oxygen through the functioning portions of the lungs and thus enables the patient to receive oxygen with greater facility.

b. *In the operating room.* Nitrous oxide and ethylene must be mixed with oxygen when used for anesthesia. The oxygen dilutes the anesthetic and at the same time gives the patient a supply of this indispensable element. Anesthesia with these substances is thus more readily controlled by mixing them with oxygen.

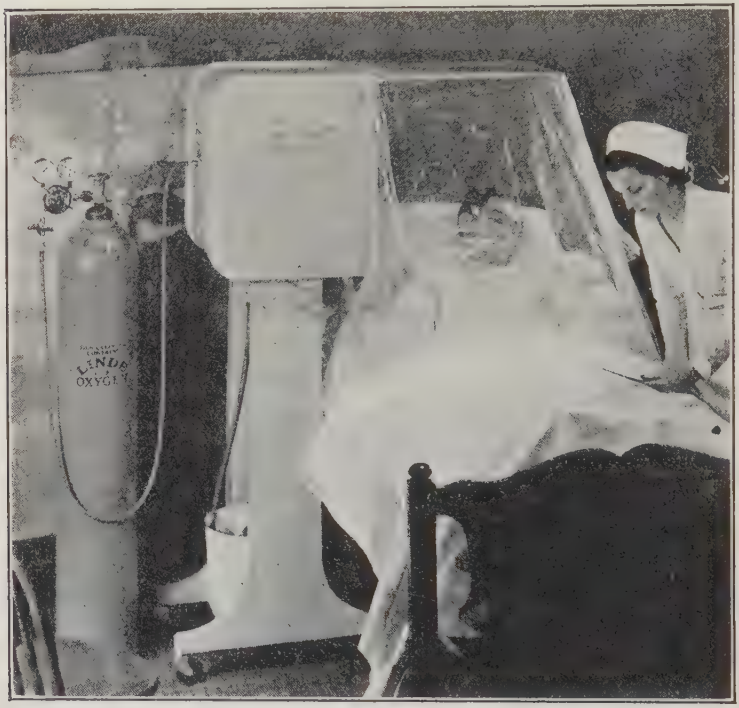


Fig. 17.—The oxygen tent. (Courtesy of the American Hospital Supply Co.)

c. *For revival of cyanosed surgical patients.* Sometimes as a result of morphine administration or prolonged anesthesia the patient immediately following an operation breathes with difficulty and becomes cyanosed. These cases are greatly benefited by the administration of a mixture containing 75 per cent oxygen and 25 per cent carbon dioxide (carbon dioxide is used because it is a respiratory stimulant, increasing the rate of respiration).

d. *In the delivery room and nursery.* Pure oxygen, also oxygen mixed with carbon dioxide, are used in the delivery room to initiate breathing in the newborn. This application of oxygen has resulted in distinct decreases in mortality of the newborn. Sometimes with premature infants it is difficult to maintain continuous respiration. The administration of pure oxygen for a period of several days after delivery is very helpful in the management of such cases.

e. *For cardiac or respiratory failure.* The oxygen tent is used to great advantage with patients having a cardiac or respiratory crisis. In these cases the administration of pure oxygen enables the patient to obtain the necessary amount of oxygen with less work being placed upon the heart and respiratory organs.

f. *In accidents interfering with respiration.* In accidents where there has occurred marked interference with respiration, such as asphyxiation by illuminating gas, or drowning, the direct administration of pure oxygen is very helpful in reviving the patient.

3. *Situations Involving Oxygen Deficiency.*—Miners who undertake rescue work following a mine accident are liable to the hazards of getting into regions where the air contains large amounts of poisonous gases. To save himself when such an atmosphere is encountered, each miner is equipped with a tank of oxygen, carried upon his back, from which he can breathe when a region of foul air is entered. Deep sea divers are also supplied with pure oxygen mixed with helium from tanks attached to their helmets by long connecting tubes.

4. *High Altitude Flights.*—The human body is adapted to carry on respiration successfully in an atmosphere of 20 per cent oxygen at altitudes varying from sea level or slightly lower to around 5,000 to 10,000 feet above sea level. As one ascends from the surface of the earth, the atmosphere becomes less dense, the oxygen tension is reduced, and breathing becomes more difficult. The body has some power of adjustment, such as by increasing the respiratory rate and the number of red cells in the blood. But these

adjustments are slow and limited. In rapid ascents to high altitudes it is therefore necessary to provide for the need of oxygen. In the stratosphere balloon flights, in which altitudes of 10 to 13 miles have been attained, the occupants of the sealed metal gondola were supplied with liquid oxygen which was allowed to evaporate at a rate that supplied their need for oxygen. Similarly high altitude aviation depends upon the use of apparatus for supplying oxygen to the occupants of the airplane. This apparatus consists essentially of a closely fitting face mask or helmet connected with an oxygen tank. The aviator applies the mask to his face and breathes pure oxygen when he reaches an altitude at which the oxygen concentration of the atmosphere is inadequate for normal respiration.

5. *Decay of Organic Matter.*—Oxygen is an important factor in the removal of organic matter from the surface of the earth by the process called decay. Decay is a slow oxidation of organic matter. It is facilitated by the action of bacteria. If it were not for the process of decay, or constant slow oxidation, the surface of the earth would soon be covered with the tissues of dead plants and animals, and life upon the earth would not be possible.

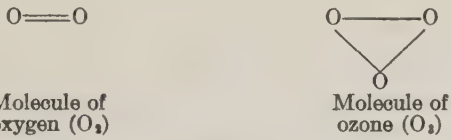
6. *Disinfectant.*—Oxygen is a great disinfecting agent. The bactericidal power of many substances, such as hydrogen peroxide and potassium permanganate, is due to the oxygen which is liberated from these compounds by chemical action. Oxygen is one of the disinfecting agents used by nature to free natural waters from microorganisms. Natural waters become polluted very much in modern times with sewage, which contains myriads of bacteria, and it is through the action of dissolved oxygen that many of these organisms are destroyed.

7. *Industrial Uses.*—As we have previously noted, hydrogen mixed with oxygen in correct proportions and ignited yields the hottest flame attainable by combustion. The oxyhydrogen torch is an important industrial application of this principle. Instead of pure hydrogen, acetylene, a hydrogen-containing compound, is now generally used, because acety-

lene is less expensive and produces a very satisfactory flame, the apparatus in this case being called the oxyacetylene torch. Pure oxygen as the supporter of combustion is necessary for the application of these industrial devices.

Ozone

Ozone may be considered as a concentrated form of oxygen. The atoms composing oxygen and ozone are identical. The essential difference between these two substances is in the number of atoms in their molecules. The oxygen molecule contains two atoms of oxygen; the ozone molecule is composed of three atoms of oxygen. This is represented graphically as follows:



Molecule of oxygen (O_2) Molecule of ozone (O_3)

Preparation.—Ozone is prepared by passing electric discharges through oxygen or air. The discharge of electric energy into oxygen gas decomposes the oxygen molecules into atoms, and these atoms combine and form molecules containing three atoms of oxygen.

$$3\ O_2 \xrightarrow{\text{Electric discharge}} 2\ O_3$$

Ozone may therefore be detected in the air following electric storms, and in the vicinity of electrical apparatus which produces "sparks," or discharges.

Properties.—Ozone is a colorless gas with a penetrating odor. It is one and a half times heavier than oxygen. It is a powerful oxidizing reagent, being more active in this respect than molecular oxygen. It is very unstable; when it decomposes, oxygen is formed. It is a strong disinfectant and bleaching agent.

From the above discussion, ozone is seen to be a special form of oxygen. The property, peculiar to certain elements, of

existing in more than one form is called *allotropism*. Sulfur, carbon, and phosphorus are examples of other elements which, like oxygen, exist in allotropic forms.

Questions for Study

1. Discuss the occurrence of oxygen.
2. Describe two methods for the preparation of oxygen.
3. What is a catalyst?
4. Give three physical and two chemical properties of oxygen.
5. What is combustion?
6. What is oxidation? Why is oxidation such an important chemical change?
7. What is an oxide? How are oxides prepared?
8. Explain how spontaneous combustion originates. Give examples.
9. What is the relationship of oxygen to life in general? What are anaerobes?
10. How is oxygen carried to the tissues of the human body?
11. The oxygen of the air is constantly being used by animals. Why does not the supply become exhausted?
12. How is the air freed from excess carbon dioxide?
13. What are the applications of pure oxygen?
14. Describe in detail the medical uses of pure oxygen.
15. What is the essential difference between oxygen and ozone?
16. What are the properties of ozone?
17. What is allotropism?

CHAPTER VIII

OXIDATION AND REDUCTION

Oxidation.—The term oxidation was first used to designate the union of oxygen with other elements. This term, however, has been extended to include other similar chemical reactions. As we now use it, oxidation includes many chemical changes in which oxygen does not take part. Thus the following reactions are considered oxidations.

1. $2\ Cu + O_2 \longrightarrow 2\ CuO$
2. $Cu + Cl_2 \longrightarrow CuCl_2$
3. $Cu + Br_2 \longrightarrow CuBr_2$

The first reaction above is an oxidation in the initial meaning of the term. The second and third reactions are oxidations in which oxygen does not take part. From these illustrations it is apparent that oxidation, as we now use the term, means more than chemical reactions in which oxygen takes a part. An examination of these three reactions reveals one underlying change that is common to all of them. This is a change in valence. The copper metal before entering into any of the three reactions is in the uncombined state, and in this state may be considered as having a valence of 0. After reacting with oxygen, or chlorine, or bromine, the valence of the copper is 2. The change of valence in copper in each case may be indicated as follows:

$$Cu^{\circ} \longrightarrow Cu^{++}$$

In each of the three reactions an increase in the positive valence of copper occurred. *Oxidation, therefore, means an increase in positive valence.*

Reduction.—We noted that the copper atoms were oxidized in the oxidation reactions above. But this is only a part of the changes that occurred. We must next consider what happened to the oxygen, the chlorine, and the bromine. When the atoms of oxygen, chlorine, and bromine reacted with copper, a valence change occurred in

them also, but in an opposite direction. The atoms of these elements underwent a *decrease in positive valence.* The changes in these elements may be indicated as follows:

1. $O^{\circ} \longrightarrow O^{--}$
2. $Cl^{\circ} \longrightarrow Cl^{-}$
3. $Br^{\circ} \longrightarrow Br^{-}$

In the first illustration above, the oxygen atoms show a decrease in positive valence and finally have a negative valence of 2; in the second and third reactions a decrease in positive valence also occurs, the chlorine and bromine atoms finally showing a negative valence of 1. The term used to indicate such valence changes is reduction. *Reduction is thus a chemical change in which there is a decrease in positive valence.*

Oxidation Involves Reduction.—Oxidation and reduction are inseparable chemical changes. One always involves the other. It is impossible to oxidize one element without bringing about a reduction in some other element. Whenever an oxidation occurs there is always a corresponding reduction.

Electron Changes in Oxidation and Reduction.—To arrive at a satisfactory understanding of oxidation and reduction we must again use our knowledge of electrons. When an element is oxidized its positive valence is increased; this means that it has lost electrons. The following examples will illustrate this:

1. $Cu^{\circ} \longrightarrow Cu^{++}$
2. $Fe^{++} \longrightarrow Fe^{+++}$
3. $Sn^{++} \longrightarrow Sn^{++++}$

In the first reaction, copper has its positive valence increased to 2; to do this, it loses 2 electrons. In the second reaction, ferrous iron, with a positive valence of 2, is changed to ferric iron with a positive valence of 3; this results from the loss of 1 electron. In the third reaction, tin, with a positive valence of 2, has its positive valence increased to 4, a change which is brought about by the loss of 2 electrons. These examples serve to illustrate that *oxidation is a chemical change in which there is a loss of electrons by an element.*

From what has been said it is evident that *reduction, which is the opposite of oxidation, is a chemical change in which there is a gain in electrons by an element.* In the examples of reductions cited, the oxidizing agents, oxygen, chlorine, and bromine, all had their positive valence decreased; this was brought about by the addition of electrons to each of these elements. Reduction thus occurs when electrons are added to an element.

Definitions.—We may now summarize what has been said in this chapter by the following definitions: *Oxidation is a chemical change in which there is a loss of electrons by an element; oxidation is, therefore, an increase in positive valence. Reduction is the opposite of oxidation. Reduction is a chemical change in which there is a gain in electrons by an element; reduction is, therefore, a decrease in positive valence.*

Questions for Study

1. What is oxidation? Give illustrations.
2. What is reduction? Give illustrations.

CHAPTER IX

WATER AND HYDROGEN PEROXIDE

Water

Occurrence.—Water is the most abundant of all compounds upon the earth. It exists in all three states of matter, solid, liquid, and gas. Three-fourths of the earth's surface is covered by water, and the atmosphere contains water vapor in considerable amounts. Water is also a large and very essential constituent of living matter. The human body is about two-thirds water, and the bodies of animals have a somewhat similar composition. Plant tissues have a water content varying from 50 to 90 per cent.

Composition.—The composition of water is as follows:

	HYDROGEN	OXYGEN
By Volume	2 parts	1 part
By Weight	2 parts	16 parts

The difference between the volume and weight ratios is explained by the fact that the atomic weight of oxygen is 16 times that of hydrogen.

Electrolysis.—The composition of water may be determined by several methods. One of the most interesting of these is electrolysis. Electrolysis is an analytical method of showing that water contains the elements hydrogen and oxygen, and the relationship between these elements by volume. The word electrolysis literally means "split by electricity." Electrolysis is the decomposition, or splitting, of water caused by passing an electric current through it.

Pure water is a very poor conductor of electricity. It is, therefore, necessary in performing electrolysis to add some substance that will enable an electric current to pass through water. For this purpose a little acid, which is a splendid carrier of electricity, is added.

The electrolysis of water is performed with apparatus such as is shown in Fig. 18. This apparatus is filled with

water to which a little sulfuric acid has been added, and an electric current is passed through the solution. As the current passes through the acidulated water, bubbles of gas appear near the two metal plates (*A*, *C*) and pass to the top of the tubes containing these plates. These plates are called *electrodes*. The electrode which is positive, in electrical terms, is called the anode; the electrode which is negative electrically is called the cathode. The gas that

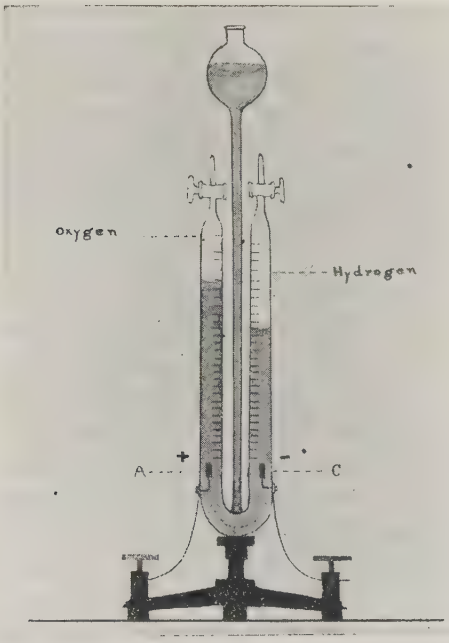


Fig. 18.—Apparatus used for the electrolysis of water.

collects in the tube containing the anode is oxygen; that in the tube containing the cathode is hydrogen. After an electric current has been passed through the acidulated water for several minutes, one can readily observe, by means of the cubic centimeter graduations upon the two collecting tubes, that the volume of hydrogen is twice that of oxygen. For every cubic centimeter of oxygen produced, there are two cubic centimeters of hydrogen formed. The gases ap-

pearing above the cathode and anode can be drawn off through the stopcocks and proved to be hydrogen and oxygen by the chemical tests previously mentioned for these elements.

Synthesis of Water.—Electrolysis is an experiment which shows the composition of water by *analysis,* a method which consists of decomposing it and identifying its elements. We can also demonstrate the composition of water by *synthesis;* that is, by putting together the elements of which it is composed. The synthesis of water may be carried out by burning hydrogen in air, or by collecting a mixture of the hydrogen and oxygen produced above in the electrolysis experiment and igniting it. If a mixture of hydrogen and oxygen in a dry test tube is ignited, the two elements will combine explosively and water will be formed upon the sides of the tube.

Physical Properties.—

1. *Color, Odor, Taste.*—Pure water is colorless and odorless. It is also tasteless, or rather tastes "flat." The pleasing taste of good drinking water is due to the small amounts of oxygen and carbon dioxide that are dissolved in it. Water with a pleasing taste can be made to taste flat by boiling, which drives off the dissolved oxygen and carbon dioxide; and the pleasing taste of fresh water can be renewed in boiled water by shaking it with air.

2. *Solvent Power.*—Water is a great solvent; that is, it has great power to dissolve substances, or make them go into solution. It is considered the universal solvent since so many substances readily dissolve in it.

Chemically pure water in the liquid state does not exist in nature. This is because water is such an excellent solvent. It dissolves greater or less amounts of almost every substance with which it comes in contact; consequently, the waters with which we are familiar contain varying amounts of mineral matter, salts, and gases in solution. These substances do not make water impure from a hygienic viewpoint; some of the mineral substances in natural waters are

essential constituents of the diet. We must, therefore, qualify the term "pure water." From the chemical point of view, pure water means the compound, whose formula is H_2O, is in a state free from all other substances. Pure water, hygienically speaking, is water free from disease-producing organisms, or poisonous substances, which make it unhealthful for drinking purposes.

3. *Freezing Point and Boiling Point.*—At 760 millimeters pressure and 0° Centigrade (32° Fahrenheit) water becomes a solid (ice); this temperature is called the freezing point of water. At the same pressure and 100° Centigrade (212° Fahrenheit) water becomes a gas (steam); this temperature is referred to as the boiling point of water. Freezing points and boiling points are influenced by both temperature and pressure. For instance, the boiling point of water at sea level (760 millimeters pressure) is 100° C., as stated above, but upon the top of Mount Blanc water boils at 85° C. because the atmospheric pressure there is much less (424 millimeters).

4. *Change of Volume and Density.*—At 4° Centigrade water is at its greatest density. It expands and becomes less dense (lighter in weight) when either heated above or cooled below this temperature. This phenomenon is unique among liquids. Most liquids expand and become lighter only when heated. The expansion of water as it is cooled below 4° C. and becomes a solid at 0° is a property of the utmost importance to marine life. If water did not grow less dense as it freezes, the ice formed, being heavier than liquid water, would sink to the bottom of the rivers, lakes, and oceans in cold weather, and the animal life of the sea would be destroyed. But, being lighter than water, ice floats on top of it, and the life of marine animals is not interfered with. The expansion of water in freezing is of further importance in nature in that it causes rocks to crumble and yield to the land their enriching mineral constituents, which are valuable for plant growth. Without this wonderful provision of nature, the fertility of the soil would not be main-

tained. This process may operate to disadvantage, however, as in the case of the bursting of water pipes from the expansion of freezing water during cold weather.

Chemical Behavior.—

1. *Stability.*—Water is a very stable compound. It is unaffected by heat until very high temperatures are reached. At temperatures below 1,000° C. it is not decomposed, and at 2,000° C. only 1.8 per cent of its molecules are dissociated into hydrogen and oxygen.

2. *Activity.*—Water reacts with most of the metallic elements and with some of the non-metals. It also reacts with many compounds.

3. *Hydrolysis.*—Another important property of water is its ability to split compounds and introduce its own constituents into the products formed. This process is called hydrolysis, a term literally meaning "split by water." For example, sodium carbonate, when dissolved in water, is slightly hydrolyzed.

$$\underset{\text{Sodium carbonate}}{Na_2CO_3} + \underset{\text{Water}}{2\,H_2O} \rightleftarrows \underset{\text{Sodium hydroxide}}{2\,NaOH} + \underset{\text{Carbonic acid}}{H_2CO_3}$$

This reaction takes place only to a slight extent, but is appreciable, and is typical of the hydrolytic action of water upon many substances. Another example of hydrolysis is the action of water upon sugars when boiled in the presence of a little acid.

$$\underset{\text{Cane sugar}}{C_{12}H_{22}O_{11}} + \underset{\text{Water}}{H_2O} \rightarrow \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Fructose}}{C_6H_{12}O_6}$$

In the above reaction, cane sugar is split by the hydrolytic action of water, and two simpler sugars, glucose and fructose, are formed.

Hydrolysis is one of the most important chemical reactions which takes place in the human body. Digestion, for example, is a series of hydrolyses, or chemical reactions in which food substances are hydrolyzed through the catalytic influence of digestive ferments.

Hydrates.—Water combines with the molecules of certain substances, forming loose chemical combinations called hydrates. Hydrates yield well-defined crystals when their solutions are allowed to evaporate slowly, and the water held in such a combination is called *water of crystallization.* This combination is not a stable one, being easily broken up by heating. For example, copper sulfate will form beautiful blue crystals when a solution of this substance is allowed to evaporate slowly. The formula for crystalline copper sulfate is $CuSO_4.5\,H_2O$. If this hydrate is heated above 200° C., its water of crystallization is driven off and a grayish white powder, whose formula is $CuSO_4$, is obtained. Examples of other hydrates are washing soda, $Na_2CO_3.10\,H_2O$; gypsum, $CaSO_4.2\,H_2O$; crystalline sodium sulfate, $Na_2SO_4.10\,H_2O$; and alum, $K_2Al_2(SO_4)_4.24\,H_2O$. The H_2O in the formula of a hydrate is set off from the rest of the formula by a period to indicate that it is loosely attached to the molecule.

Anhydrous, Dehydration, Efflorescence, Deliquescence.—*When the water of crystallization has been removed from a hydrate, the resulting compound is said to be anhydrous,* a term which means "without water." *The removal of water from a compound is called dehydration.* Thus heating crystalline copper sulfate ($CuSO_4.5\,H_2O$) to 200° C. dehydrates this compound and the resulting substance is anhydrous copper sulfate ($CuSO_4$). Some hydrates will not give up their water of crystallization unless placed in very dry air or heated; others liberate their water spontaneously without any treatment. *If a substance gives up its water of crystallization when exposed to the air at ordinary conditions of temperature, pressure, and moisture, it is said to be efflorescent. If, on the other hand, a substance takes up moisture from the air at ordinary temperatures and pressures, it is said to be deliquescent.* Some substances, like sodium hydroxide or calcium chloride, are so deliquescent that they will soon dissolve completely in the water which they absorb from the air and consequently must be kept in well-

stoppered bottles. Deliquescent substances obviously make excellent drying agents.

Plaster of Paris.—A very important hydrate is gypsum, $CaSO_4.2\,H_2O$, the dehydrated form of which is "plaster of Paris." The latter substance is used extensively in surgery in making casts for artificially supporting body structures until natural processes have completed their repair. It is also used in making masks, busts, molds, and various decorative objects of art. The chemistry of the "setting" of plaster of Paris is the absorption of water and consequent formation of the crystalline hydrate, gypsum, which is firm and hard. The process is represented by the following equation:

$$\underset{\text{Plaster of Paris (a soft powder)}}{(CaSO_4)_2.H_2O} + \underset{\text{Water}}{3\,H_2O} \rightarrow \underset{\text{Gypsum (a hard crystalline substance)}}{2\,CaSO_4.2\,H_2O}$$

When plaster of Paris is mixed with about one-third its weight of water, a thick paste is formed which "sets" in ten to fifteen minutes, forming hard crystalline gypsum. In setting, the paste expands slightly and forms a tight cast, or an exact reproduction of a mold.

Hard and Soft Waters.—Water containing calcium or magnesium salts in solution is called hard water. If soap is added to hard water, it combines with calcium or magnesium and forms an insoluble curd, which is precipitated from solution. As long as water is hard it precipitates soap and prevents the action of soap as a cleansing agent. The hardness of water is, therefore, appropriately referred to as its "soap destroying power." Soft waters are those which contain little or none of these lime salts. Rain water and waters that have never percolated through earths containing calcium or magnesium compounds are soft waters.

Hardness of water may be temporary or permanent. Temporary hardness is due to the presence of calcium or magnesium bicarbonates. Temporary hard waters are softened by boiling, or by adding chemicals like lime or washing soda. Boiling removes temporary hardness by decompos-

ing the bicarbonates of magnesium or calcium, liberating carbon dioxide gas, and precipitating the magnesium or calcium from solution as insoluble carbonates. The removal of temporary hardness by boiling is illustrated by the following equation:

$$\underset{\text{Calcium bicarbonate (soluble)}}{Ca(HCO_3)_2} + \text{heat} \rightarrow \underset{\text{Calcium carbonate (insoluble)}}{CaCO_3\downarrow} + H_2O + \underset{\text{Carbon dioxide}}{CO_2\uparrow}$$

The addition of chemicals also removes temporary hardness of water by forming precipitates with magnesium or calcium. This method is practical and inexpensive, and consequently is used in communities where the natural waters require softening.

Permanent hardness of water is due to calcium or magnesium in solution as chlorides or sulfates principally. This type of hardness cannot be removed by boiling and is dissipated only by adding chemicals which will precipitate magnesium or calcium. Washing soda (sodium carbonate) is used to remove permanent hardness. The reaction is represented by the following equation:

$$\underset{\text{Calcium chloride (soluble)}}{CaCl_2} + \underset{\text{Sodium carbonate}}{Na_2CO_3} \longrightarrow \underset{\text{Calcium carbonate (insoluble)}}{CaCO_3\downarrow} + \underset{\text{Sodium chloride}}{2\,NaCl}$$

Objections to Hard Water.—Soaps will not cleanse in hard waters. This is because hard water precipitates the soap as an insoluble curd. As long as a water is hard it will precipitate or "destroy" soap, and consequently the cleansing action of soap cannot take place until all the hardness has been removed. Of course, soap may be used first to soften water and then to act as a cleansing agent, but the use of soap as a softening agent is quite expensive. One gram of lime (CaO) will precipitate 10 grams of ordinary soap. This fact indicates that the removal of hardness of water by the use of soap would not be economical and, moreover, the insoluble curd produced by hard water and soap is undesirable in the laundering process. Substances

other than soaps are, therefore, indicated for the softening of hard waters. Satisfactory softening agents must be inexpensive and should not leave a floating, insoluble curd, as in the case of soaps. Sodium carbonate, lye, and lime are the substances most generally used for softening hard waters.

Purification of Water

Chemically Pure Water—Distillation.—Water that is used in scientific laboratories, in the electric storage batteries of lighting systems, automobiles, radios, etc., and in many manufacturing processes must be free from the mineral matter and organic substances that are present in greater

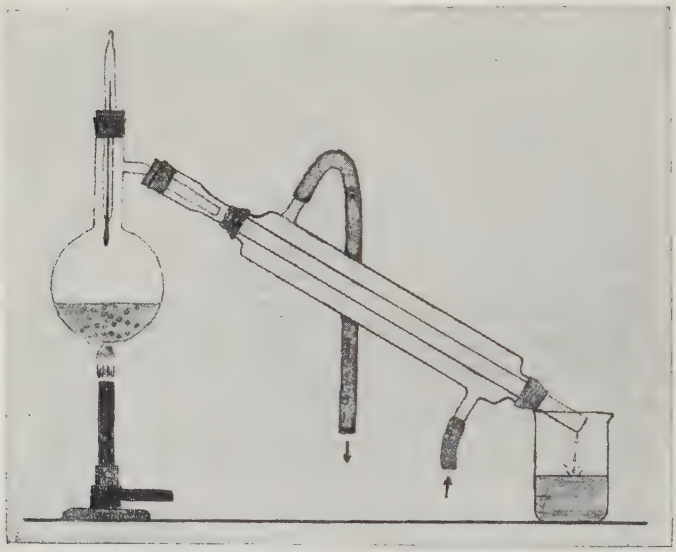


Fig. 19.—Diagram showing distillation of water.

or less quantities in all natural waters. The purification of water for scientific and industrial purposes is accomplished by a process known as distillation. In principle, distillation consists of heating water until it reaches the boiling point and becomes a vapor, and then passing it through a cooling chamber where it is cooled below the boiling point and be-

comes a liquid again. In this process water is separated from all substances whose boiling points are higher than the boiling point of water (100° C.). Water can be freed in this manner from all solids and most liquids; and the only substances remaining in ordinary distilled water are a few gases, such as carbon dioxide, oxygen, and possibly ammonia and hydrogen sulfide, which have lower boiling points than water, and consequently will distill along with the water. To obtain water of the highest purity requires discarding of certain fractions of the first distillation and redistillation of the purest fraction. Water that has been distilled once, however, is pure enough for most experimental and practical work; highly purified water is not essential except for very special chemical work. Distilled water is undesirable as a drinking water, since it does not contain essential mineral salts.

Uses of Water in the Human Body.—Water has many important functions in the human body. The chief ones are as follows:

1. It aids in the digestive process.
2. It carries digested food products in solution to the tissues.
3. It removes waste products from the cells and carries them to the proper excretory organs.
4. It distributes internal secretions.
5. It is an essential constituent of body tissues and body fluids.
6. It aids in the dissipation of excessive heat and thus assists in the regulation of body temperature.

The individual cells of the body may be considered as living units, largely composed of, and surrounded by, water, from which they receive their food; in which they carry on their vital activities; and into which they discharge their waste products.

Water Balance in the Human Body

Water is supplied to the body through the fluids drunk and the foods ingested. Foods contain considerable water as

such and they also yield water when oxidized. In undergoing the various transformations to which it is subjected in the body, 1 gram of food yields about 0.9 gram of water.

Water in the liquid state is excreted from the body in the urine, the feces, and the sweat. It is also eliminated from the outer surfaces of the body and through the lungs in the form of water vapor which is not ordinarily perceptible.

Normally a balance between intake and output of water is maintained when the human subject is in health and has free access to water. In many illnesses, however, water balance becomes a problem and the maintenance of a normal water balance in the patient is an important responsibility of the physician and the nurse. The patient is definitely in an unfavorable state of dehydration when there has occurred a water loss equal to 6 per cent of the body weight, and a water loss equivalent to 20 per cent of the body weight is incompatible with life.

If water cannot be taken by mouth, an adequate quantity is administered parenterally. (The importance of making parenterally-administered fluids to contain physiologic concentrations of salt or nutrients is discussed on page 129.) An unfailing guide is to see that there is a normal excretion of urine. There should be a urinary output of 1,000 to 1,500 c.c. per twenty-four hours to eliminate the 30 to 70 grams of waste products which pass through the kidneys.

Hydrogen Peroxide—H_2O_2

Preparation.—Hydrogen peroxide is prepared by the action of sulfuric acid upon barium peroxide.

BaO_2	+	H_2SO_4	→	$BaSO_4$	+	H_2O_2
Barium peroxide		Sulfuric acid		Barium sulfate		Hydrogen peroxide

Properties.—Hydrogen peroxide is a colorless liquid, with a faint odor resembling ozone, and a bitter, astringent taste. It mixes with water in all proportions. It is an unstable compound, decomposing readily with the liberation of oxygen and the formation of water.

$$2\ H_2O_2 \rightarrow 2\ H_2O + O_2$$

Its decomposition is quite rapid when exposed to light, or to the air, hence it is kept in well-stoppered, dark colored bottles. It keeps best in dilute solutions to which a small amount of acid and a trace of acetanilid have been added. The U. S. Pharmacopeia preparation is a 3 per cent solution containing a little phosphoric acid and acetanilid as preservatives. As hydrogen peroxide liberates oxygen when it decomposes, it is an important oxidizing agent.

Uses.—Hydrogen peroxide is used for bleaching, and as a disinfectant and an antiseptic. All these applications are due to its oxidizing property. It is used for bleaching silks, feathers, hair, oil paintings, and various delicate materials. Its value as a bleaching agent is due, not only to its mild oxidizing properties, but also to the fact that it leaves a perfectly harmless substance, water, as the end-product of its action. When mixed with blood or pus, hydrogen peroxide liberates nascent oxygen very rapidly, hence it is applied to wounds as a disinfectant. It undoubtedly has the power to destroy microorganisms, but its ability as a disinfectant has been overestimated. It is of considerable value in cleaning wounds, because of its property of effervescing, or releasing oxygen bubbles, but it does not penetrate deep enough into a wound to disinfect it properly. For the thorough disinfection of wounds, more penetrating and more potent disinfectants are greatly to be preferred.

Questions for Study

1. Discuss the occurrence of water.
2. What is the composition of water by volume? By weight?
3. Describe the electrolysis of water. What does it show regarding water?
4. What is meant by synthesis? How is the synthesis of water carried out?
5. Mention five properties of water. How does water compare with other substances in solvent power?
6. Distinguish between hygienically pure and chemically pure water.
7. Water becomes less dense when it freezes. What is the importance of this property in nature? Of what value is the expansion of water when freezing?
8. What is hydrolysis?

9. What is a hydrate?

10. Define: anhydrous, dehydration, efflorescence, deliquescence.

11. What are the uses of plaster of Paris? Explain the chemistry of the setting of plaster of Paris.

12. Distinguish between hard and soft waters. What are the objections to hard water? How is hardness of water removed?

13. Describe the process of distillation of water.

14. What are the uses of water in the human body?

15. How does the body obtain water?

16. How is water eliminated from the body?

17. How much loss of water from the body will produce a dangerous state of dehydration?

18. What guiding principle is followed in maintaining an adequate water intake in patients who cannot take fluids by mouth?

19. What are the properties of hydrogen peroxide? What are its uses?

20. Is hydrogen peroxide a good disinfectant?

UNIT IV

SOLUTIONS AND BEHAVIOR OF MATTER IN SOLUTION

CHAPTER X

SOLUTIONS, COLLOIDS, DIALYSIS AND OSMOSIS

Definition of Solution.—*A solution is a homogeneous mixture of two or more substances.* By homogeneous is meant uniformly mixed, or alike in all parts. In a solution the molecules of each substance are uniformly distributed with respect to each other; or in other words, any part of a solution has exactly the same composition as any other part, provided the temperature of all parts is the same. For example, if we place some common salt in the bottom of a beaker and fill the beaker with water, the salt dissolves, as we say, and a solution is formed. What happens is that the attraction between the salt molecules is overcome by a greater attraction between the salt and water molecules, and the result is that the salt molecules spread themselves uniformly through the water. If, after solution has taken place, we remove equal samples of the mixture from the top, or bottom, or midregion, or any part of the beaker, and evaporate them to dryness, we will obtain the same amount of salt in each of the samples. This shows that the salt was uniformly mixed with the water.

A solution has two parts, the *solute* and the *solvent*. As we ordinarily think of them, the solute is the part present in the smaller amount, and the solvent is the substance present in the greater quantity. However, we can often reverse the relative amounts of the substances present in a solution and thus make the part that was called the solvent become the solute and vice versa.

Solubility.—The solubility of a substance means the amount of that substance which will dissolve in a specified

solvent. If the solvent is not mentioned, it is understood to be water. Solubility is generally expressed as the number of parts of solute that will dissolve in 100 parts of solvent, and as temperature affects solubility, the temperature is usually mentioned for the solubility given. If the temperature is not stated in connection with a solubility, room temperature (20-25° C.) is understood to be the condition.

Factors Determining Solubility.—Whether a substance will dissolve and form a solution is based upon three things:

1. *Nature of Solvent and Solute.*—The nature of the solvent and of the solute has a determining influence upon solubility. Some substances are highly soluble in water, while others are slightly soluble, or highly insoluble in this solvent. Other substances will dissolve best in alcohol, ether, chloroform, or benzene.

2. *Temperature.*—A marked influence is exerted by temperature. The solubility of most solids in water is increased by heating, but some are little affected by temperature change, and a few are less soluble in hot water than in cold water. Thus 100 c.c. of water will dissolve 13 grams of potassium nitrate at 0° C., and 246 grams of the same substance at 100° C. At 0° C., 36 grams of sodium chloride will dissolve in 100 c.c. of water, but only 39 grams of this material will dissolve at 100° C. Calcium hydroxide, on the other hand, is only about half as soluble at 100° C. as at 20° C. For gases dissolved in liquids there is but one rule in regard to temperature: increasing the temperature decreases their solubility.

3. *Pressure.*—Pressure has practically no influence upon the solubility of solids or liquids in water, but an increase in pressure increases the solubility of gases.

Concentration—Saturated and Supersaturated Solutions.—The concentration of a solution means the amount of solute dissolved in the solvent. *A dilute solution* contains a small amount of solute. *A concentrated solution* is one that contains a large amount of dissolved substance. When a solvent has dissolved all of the solute it can contain, the solu-

tion is said to be saturated. *A saturated solution* contains the greatest amount of solute it can hold under the existing conditions. *A supersaturated solution* contains more solute than its solvent holds under normal conditions. It is prepared by dissolving, with the aid of heat, a greater amount of solute than the solvent will contain at ordinary temperatures, and then allowing it to cool. If cooled very slowly, without agitation, the solvent will hold in solution for

TABLE IV

FAMILIAR SOLUTIONS

TYPE OF MIXTURE	SOLUTE	SOLVENT	SOLUTION
SOLIDS IN LIQUIDS	Sodium chloride	Water	Aqueous sodium chloride
	Fat	Ether	Ethereal solution of fat
	Iodine	Alcohol	Alcoholic solution of iodine (tincture of iodine)
LIQUIDS IN LIQUIDS	Alcohol	Water	Aqueous solution of alcohol
	Ether	Alcohol	Alcoholic solution of ether
GASES IN LIQUIDS	Carbon dioxide	Water	Aqueous solution of carbon dioxide ("carbonated water")
	Ammonia	Alcohol	Alcoholic solution of ammonia (aromatic spirits of ammonia)

a time a greater amount of solute than is held by a saturated solution under normal conditions, hence it is called a supersaturated solution. Supersaturated solutions are not stable; they readily give up their excess solute if shaken, or if a few crystals of solute are added.

Crystalloids and Colloids.—If we dissolve gelatin in water, we obtain a solution which has special properties. This solution appears thick and viscous; it is somewhat opalescent; and, if sufficiently concentrated, it will set to a jellylike mass. We can pour it through an ordinary filter paper but, if we attempt to pass it through parchment paper, the water

will pass through but the gelatin will remain on the filter. The parchment membrane has a texture too fine for gelatin particles to filter through. The gelatin particles must, therefore, be much larger than the molecules of such substances as glucose, sodium chloride, or hydrochloric acid, which will readily pass through parchment. *Substances which pass through membranes like parchment when in solution are called crystalloids. Substances which will not pass through parchment-like membranes are known as colloids.* Glucose, sodium chloride, and hydrochloric acid are examples of crystalloids; gelatin, glue, egg albumen, and caramel are examples of colloids. In addition to parchment paper, crystalloids and colloids behave similarly with respect to a number of other membranes. Bladder, intestine, egg membrane, cellophane and collodion are examples of membrane materials through which crystalloids will pass but colloids will not.

A liquid containing colloidal particles in suspension is known as a colloidal solution. A true solution differs from a colloidal solution in the size of the dissolved or suspended particles. In a true solution the dissolved molecules are small and will readily pass through a parchment paper. In a colloidal solution the suspended particles are either very large molecules, or are particles composed of many molecules, neither of which will pass through membranes with a texture like that of parchment paper.

The term colloid then indicates a state of matter. It refers to matter subdivided into particles ranging in size from 1 to 100 millimicrons. (A millimicron is one-millionth of a millimeter, or one-twenty-five millionth of an inch.) The average colloidal particle is about one thousand times smaller than a red blood cell, or an anthrax bacterium. Such particles cannot be seen with a high power microscope, but can be made apparent to the eye with an instrument called the ultramicroscope, which does not show actual colloidal particles, but reveals their presence by zigzag reflections the particles produce while moving rapidly in a highly illuminated field.

One of the most interesting and important properties of colloids is their power to absorb large quantities of water. This is called *imbibition.* It occurs in living cells, and is the process which enables the tissues to hold such relatively large quantities of water. The human body is about three-fourths water, and yet the tissues are quite firm and solid. Such quantities of water could never be maintained if the cells did not contain a large amount of substances in the colloidal state.

Dialysis.—In studying the chemistry of living things, it is necessary to get clearly in mind the principles involved in the passage of materials through membranes. In the human body the absorption of water, salts, food substances, etc., takes place through the mucous membranes of the intestinal walls, which are examples of living membranes; the blood corpuscles carry on their functions through processes involving their membranous walls; respiration takes place through the thin membranous plates of the lung alveoli; the excretion of urine takes place through membranes which line the kidney glomeruli and tubules; and many other processes occur, which involve the activity of living membranes. The cells of plants have walls which are typical living membranes, and the plant is dependent for its foods upon the passage of materials through its membranous cell walls. The phenomena associated with the passage of materials through membranes are, therefore, of great significance in biological chemistry.

In studying the diffusion of materials through membranes, no difficulty will be experienced if the student will keep in mind the two points brought out above under colloids, namely: (1) the size of the molecules of the diffusing substance; and (2) the texture of the membrane through which substances pass. As we noted above, the essential difference between crystalloids and colloids is that crystalloids have a much smaller molecule. If a solution containing both crystalloids and colloids is placed in a parchment bag, and the latter is tied securely and suspended in a beaker of distilled water, as shown in Fig. 20, the crystalloids will pass through

the parchment into the distilled water and in this manner can be separated from the colloids. *The separation of crystalloids from colloids by the passage of the crystalloids through a membrane which holds back colloids is called dialysis.* A very small amount of colloidal particles may pass through a parchment membrane in time, but they pass so slowly that dialysis is considered a practical process for the separation of crystalloids from colloids. Membranes other than parchment may be used to demonstrate dialysis, such as a cellophane or collodion bag, or a pig's bladder.

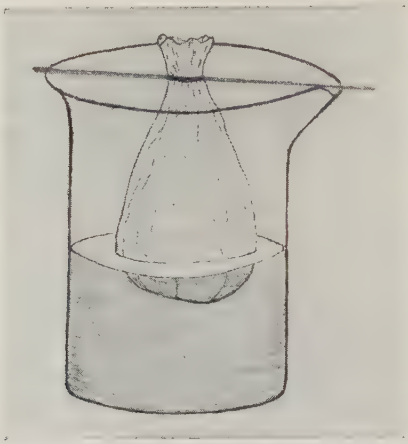
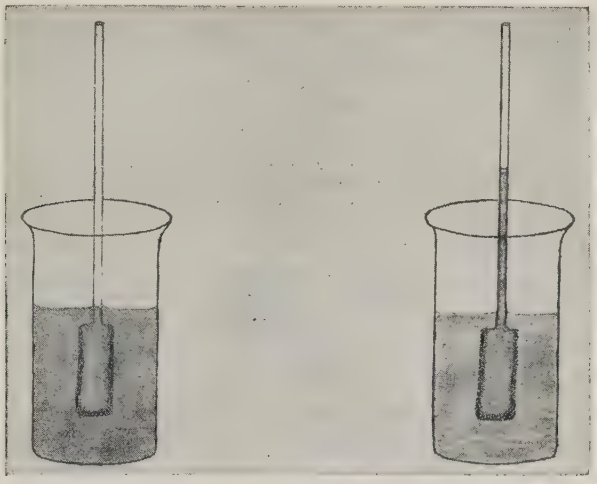


Fig. 20.—Dialyzing apparatus.

Osmosis.—If we impregnate the walls of a clay cup with copper ferrocyanide, we have a membrane through which neither crystalloids nor colloids can diffuse, and through which only water can pass. Such a membrane is called a semipermeable membrane; it is permeable to the solvent (water) but not permeable to the solute. It is, therefore, "semi" or half permeable.

If a solution of cane sugar is placed in a semipermeable cup into which a long glass tube has been sealed, and the cup is immersed in a beaker of distilled water, the water will rise in the glass tube as shown in Fig. 21. This process is called osmosis. *Osmosis may be defined as the passage of*

the solvent through a membrane not permeable to the solute, the direction of the greater flow being from the less concentrated solution to the more concentrated solution. The pressure which produces osmosis is called *osmotic pressure.* All substances that are soluble in water will bring about the phenomenon of osmosis when placed in the proper relation to a semipermeable membrane. The osmotic pressure of a solution is proportional to the number of dissolved particles.



Beginning of experiment Later in experiment

Fig. 21.—Experiment to demonstrate osmosis.

To explain osmosis we must use the principles emphasized above, namely, the size of molecules and the nature of the membrane involved. Within the cup, shown in Fig. 21, there are water molecules and sugar molecules; on the outside of the cup there are water molecules only. The walls of the cup constitute a semipermeable membrane. Water can pass through this membrane but the sugar molecules cannot. As a result, the water passes faster into the cup than out of it, since there are sugar molecules in the cup which interfere with the outward passage of the water. Therefore, the volume of water in the cup will increase and the water will rise in the tube.

The principle of osmosis has many applications. In plants osmotic pressure causes water to pass from one cell to another, and thus aids the plant in absorbing and distributing the water that is so necessary for its activities. It is this principle which enables a tree to obtain for its topmost branches their necessary water supply. In the human body osmosis brings about a uniform distribution of fluids throughout the tissues. The concentration of salts in the human body is approximately equivalent to 0.85 per cent of sodium chloride. It is very important for this concentration to be maintained, and changes in the amount of salts in any part of the body are quickly adjusted to the normal concentration by osmosis.

Physiological Salt Solution; Ringer's Solution.—The normal concentration of salts in the blood and lymph of animals is approximately equivalent to 0.85 per cent of sodium chloride. The living tissues of animals undergo no change from osmosis in a solution of this strength. *An 0.85 per cent solution of sodium chloride is, therefore, called a physiological salt solution.* A solution of the same concentration of sodium chloride, but containing in addition 0.03 per cent of potassium chloride, 0.02 per cent of sodium bicarbonate, and 0.02 per cent of calcium chloride, is known as Ringer's solution. Ringer's solution, besides being physiologically balanced with respect to osmotic pressure, contains the elements calcium and potassium and a trace of alkali, additional factors under the influence of which a living tissue, such as muscle, will survive much longer.

Isotonic, Hypotonic, and Hypertonic Solutions.—Solutions having the same osmotic pressure are known as isosmotic, or *isotonic,* solutions. (*Isos* is a prefix meaning equal.) *Physiological salt solution is isotonic to the tissues of the body.*

A solution is said to be *hypotonic* to another solution when it has a lower osmotic pressure (*hypo* means below), and a solution is *hypertonic* to another solution when it has a higher osmotic pressure (*hyper* means above). A solution

with a lower osmotic pressure than blood plasma (lower than physiological salt solution) is hypotonic to the blood; a solution with a higher osmotic pressure than blood plasma is hypertonic to the blood.

Blood Changes Due to Osmosis.—The behavior of blood corpuscles, when placed in solutions of different concentrations, is an interesting demonstration of osmosis. If blood corpuscles are placed in a physiological salt solution, they will maintain their normal size and shape. This is illustrated by position *A* in Fig. 22. There is no change in the corpuscles in this solution because the concentration of salt is the same within the cells as on the outside, and consequently water will pass through the walls of the corpuscles with the same rapidity in each direction.

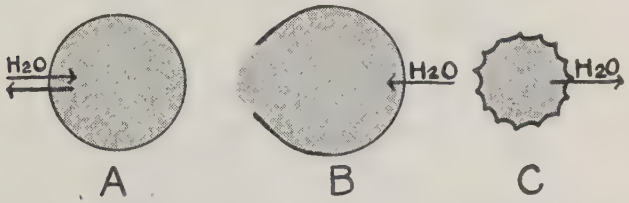


Fig. 22.—Diagram showing changes in blood cells due to osmosis. *A*, Blood corpuscle in isotonic solution (0.85 per cent NaCl). No change in volume. *B*, Blood corpuscle in hypotonic solution (distilled water). Swells and bursts. *C*, Blood corpuscle in hypertonic solution (2 per cent NaCl). Shrinks and becomes crenated.

If blood corpuscles are placed in distilled water, which represents a hypotonic solution, they will swell up and burst. The explanation here is that there is a greater concentration of salts within the blood cells. Osmotic pressure causes water to pass into the cells more rapidly than it passes out, since in osmosis the greater flow is toward the more concentrated solution; consequently, the cells swell from increased fluid until they rupture. This is illustrated by position *B* in Fig. 22. Distilled water is not the only medium that will bring about this change; any salt solution that is appreciably lower in concentration than 0.85 per cent will produce a like change. The rupture of red blood corpuscles by a hypotonic salt solution (or other factors) is called *hemolysis*.

If blood corpuscles are placed in a hypertonic solution, e.g., a 2 per cent solution of sodium chloride, their contents will shrink in volume and they will have the appearance represented by position *C* in Fig. 22. This change is explained again by the principle of osmosis. The greater concentration of salt this time is on the outside of the cells. Water will, therefore, pass out of the cells faster than it can pass into them, and the result is a withdrawal of water from the cells with consequent shrinking of the latter. The shrinking of blood cells in a hypertonic salt solution is called *crenation* (see Fig. 23).

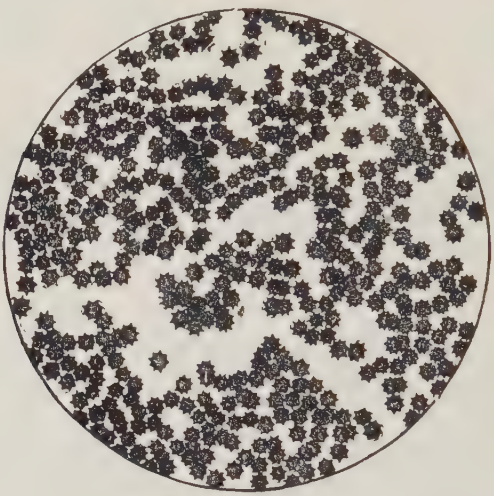


Fig. 23.—Crenated erythrocytes. A microscopic view showing the shrinking of red blood cells when placed in a hypertonic salt solution. (From Hawk and Bergeim: *Practical Physiological Chemistry,* 1937. Courtesy of P. Blakiston's Son & Co.)

From the above discussion, it is apparent that *fluids cannot be safely introduced into the blood stream unless they are practically isotonic to the blood.* Sometimes it is necessary to give water, or salt, or glucose to a patient intravenously. In such instances sterile isotonic solutions of salt or glucose are used. When drugs are administered intravenously, care must be exercised to use a solution that is of a concentration not far from isotonic, or else place the substances in physio-

logical salt solution. Sterile physiological salt solution is used also in surgery for cleaning wounds, washing out the peritoneal cavity, etc. In all of these applications, the use of physiological salt solution is based upon the fact that the tissues undergo no changes from osmosis in this solution.

The phenomena concerning the behavior of blood cells are typical of any cell possessing a cell wall which acts as a semipermeable membrane. It is especially characteristic of plant cells.

Questions for Study

1. Define a solution. What are the two parts of a solution?
2. What is meant by solubility?
3. What are the factors which influence solubility?
4. What is a dilute solution? A concentrated solution? A saturated solution? A supersaturated solution?
5. What is a crystalloid? A colloid? Give examples of each. Distinguish between a colloidal solution and a true solution.
6. Define dialysis.
7. What is osmosis? Give an explanation of osmosis.
8. What is the importance of osmosis in relation to the human body? To plants?
9. What is a physiological salt solution?
10. Define isotonic, hypotonic, and hypertonic solutions.
11. What changes will take place in blood cells when placed in a hypotonic solution? When placed in a hypertonic solution? Explain each case.
12. What are the uses of physiological salt solution? Explain the necessity for its use in each case.

CHAPTER XI

ELECTROLYTES AND IONIZATION

Electrolytes.—From the standpoint of electrical conductivity we may establish two very important classes of compounds: electrolytes and non-electrolytes. *Electrolytes are substances which conduct an electric current when in solution.* They are acids, bases, and salts. They belong to the division of inorganic compounds, although some organic compounds, notably the proteins, organic acids, and organic salts, are characteristic electrolytes. *Non-electrolytes are substances which will not carry an electric current when in solution.* Most organic compounds are non-electrolytes. Examples of non-electrolytes are sugars, starches, fats, and alcohols.

Ionization

Electrolytes, when in solution, undergo a very important change; their molecules are split into particles which bear charges of electricity and act as independent units when a chemical change takes place. These particles are called ions, and the cleavage of molecules into ions is called ionization, or electrolytic dissociation. An ion in most cases is a single atom which bears one or several electric charges; some ions, however, consist of many atoms which hold their electric charge, or charges, in common. The name "ion" comes from a Greek word meaning "going." It was applied to these individual particles of electrolytes because they are in a rapid state of motion in a solution, and go to oppositely charged electrodes under the influence of an electric current.

To illustrate, let us take a solution of hydrochloric acid in water. The ionization of hydrochloric acid is represented by the following equation:

$$HCl \rightleftarrows \overset{+}{H}, \quad \overset{-}{Cl}$$

Put in words, the above equation has the following interpretation: One molecule of hydrochloric acid in solution

separates into one hydrogen ion bearing a positive (+) charge, and one chlorine ion bearing a negative (–) charge. The arrows are made to point both ways, because some hydrogen and chlorine ions recombine and form molecules of hydrochloric acid, while other molecules of hydrochloric acid are dissociating, and, consequently, a solution of hydrochloric acid always contains hydrogen ions, chlorine ions, and molecules of undissociated hydrochloric acid.

As a second example, let us consider sulfuric acid in water.

$$H_2SO_4 \rightleftarrows \overset{+}{H}, \quad \overset{+}{H}, \quad \overset{=}{SO_4}$$

The above equation indicates that 1 molecule of sulfuric acid dissociates into 2 positively charged hydrogen ions and 1 negatively charged sulfate ion; the sulfate ion, consisting of 5 atoms, behaves like a single unit and carries two negative charges. A solution of sulfuric acid always contains hydrogen ions, sulfate ions, and undissociated molecules of sulfuric acid; hence the arrows in the equation point both ways.

When an electric current is passed through a solution of an electrolyte, the positive ions go to the cathode or negative pole, and the negative ions pass to the anode or positive pole. Positive ions are therefore called *cations* because they migrate to the cathode when an electric current is passing through a solution; and negative ions are called *anions* since they pass to the anode under the influence of an electric current.

The essential features of the ionization theory are outlined in the following summary:

1. The molecules of electrolytes (acids, bases, and salts) dissociate, when in solution, into ions. The process is called ionization.

2. Ions bear positive or negative charges of electricity. The number of positive charges held by positive ions in a solution of an electrolyte is exactly equal to the number of negative charges held by negative ions in the same solution. A solution of an electrolyte is, therefore, electrically neutral.

3. Ions are the individual carriers of an electric current through a solution. When a current of electricity flows through a solution of an electrolyte, the positive ions pass to the negative pole and the negative ions go to the positive pole. The behavior of ions in this respect is shown diagrammatically in Fig. 24.

4. Chemical reactions involving electrolytes in solution are reactions between ions. This is an extremely important conception and must be used in interpreting all chemical reactions of electrolytes. In every reaction between electrolytes, the student must visualize the individual ions, and

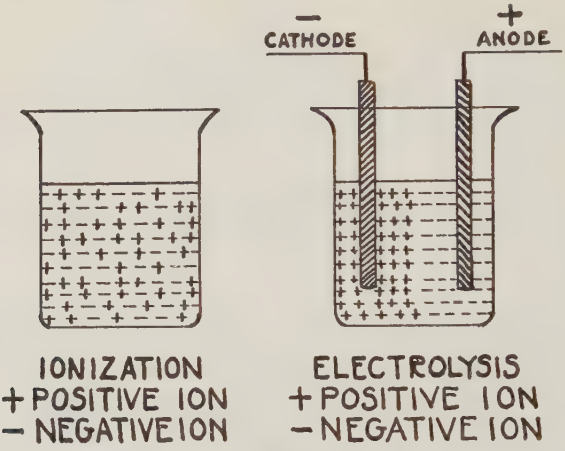


Fig. 24.—Diagram showing ionization and electroylsis.

not the molecules, as the reacting particles. For instance, take the reaction between sodium chloride and silver nitrate; these substances ionize as follows:

$$\underset{\text{Sodium chloride}}{NaCl} \rightleftarrows \overset{+}{Na}, \quad \overset{-}{Cl}$$

$$\underset{\text{Silver nitrate}}{AgNO_3} \rightleftarrows \overset{+}{Ag}, \quad \overset{-}{NO_3}$$

A chemical reaction between these substances involves the four ions shown above. Each of these ions comes in con-

tact with any of the others, and, therefore, has the possibility of reacting with any of them. The result will be a combination between the ions which have the greatest affinity for each other, and is represented by the following equation:

$NaCl$	+	$AgNO_3$	→	$NaNO_3$	+	$AgCl$
Sodium chloride		Silver nitrate		Sodium nitrate		Silver chloride

5. The number of charges upon an ion is equivalent to its valence.

The Nature of Ions.—From the above discussion it is evident that ions are a special state of matter, and are quite different from atoms. For example, let us consider sodium chloride, which ionizes in water as follows:

$$NaCl \rightleftarrows \overset{+}{Na}, \overset{-}{Cl}$$

The sodium ion has properties that are quite different from those of the sodium atom. Sodium atoms, it will be recalled, decompose water, liberating hydrogen; sodium ions exist in water and do not attack it. Chlorine in the atomic state is a greenish gas, with a poisonous action upon living matter, and when dissolved in water is an excellent disinfectant; the chlorine ion, however, is a harmless particle in solution, and is, in fact, an essential constituent of the fluids which bathe living tissues.

Such differences in behavior are quite marked and therefore must be due to fundamental differences in the nature of the ion and the atom. To understand the differences in the behavior of ions and atoms we must consider the electron structure of these two particles of matter. The differences in the structure of the atoms and ions of sodium and chlorine are shown in Fig. 25. The nuclei of the sodium atom and the sodium ion are the same. The differences in these two particles are to be found in their electrons. The sodium atom contains 11 electrons; the sodium ion contains 10 electrons. In the process of ionization the sodium atom loses one electron from its outermost orbit. The sodium ion

and the sodium atom are, therefore, different substances structurally, hence one would expect them to manifest different properties.

The chlorine atom contains 17 electrons. The negatively charged chlorine ion contains 18 electrons. Here again we find a difference in structure. This difference in structure is a fundamental one and accounts for the difference in properties of the chlorine atom and the chlorine ion.

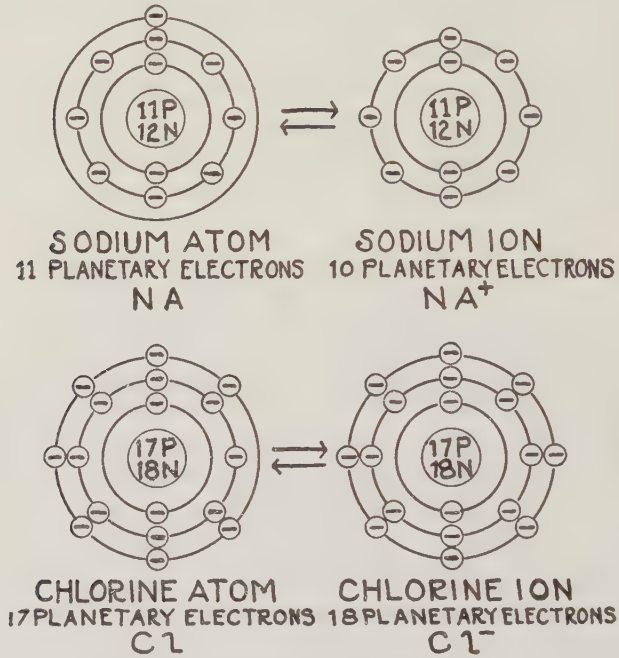


Fig. 25.—Diagram showing differences between the atom and the ion of sodium and chlorine.

The diagrams of Fig. 25 also show why the sodium ion is positive and the chlorine ion is negative. The neutral sodium atom contains 11 protons in its nucleus. This number of positive particles is balanced by the 11 electrons in its orbits. (The student should verify these figures by counting the protons and electrons in the diagrams.) This balance of protons, or positive charges, by electrons, or negative charges, accounts for the neutrality of the sodium atom. In under-

going ionization the sodium atom loses an electron. The sodium ion contains 11 protons and 10 electrons. The difference between the number of protons and electrons in the sodium ion is 1, and is in favor of the protons. Thus there is 1 unbalanced proton in the nucleus of the sodium ion which gives the latter a positive charge of 1.

The neutral chlorine atom contains 17 protons in its nucleus and 17 electrons in its orbits. (The student should again verify these figures by the diagrams of Fig. 25.) Here again we find a balanced condition. The number of protons in the neutral chlorine atom is equal to the number of its electrons; hence the chlorine atom is neutral. The negative chlorine ion contains 17 protons in its nucleus and 18 electrons in its orbits. The difference in the number of charges here is 1, and is in favor of the electrons; hence the chlorine ion has a negative charge of 1.

These differences in structure show why ions are positive or negative. *When there are more protons than electrons in an ion, the ion will be positive; when there are more electrons than protons in an ion, the ion will be negative. The numerical difference between the number of protons and electrons in the ion corresponds to the number of charges upon the ion.* Thus, if the difference between the number of protons and electrons is 1, the ion will bear a charge of 1; and it will be positive if the protons are in excess, or negative if the electrons are in excess. Similarly, if the difference between the number of protons and electrons in an ion is 2, or 3, or 4, the number of charges upon that ion will be 2, or 3, or 4, respectively, the ion being positive if protons are in excess, or negative if electrons are in excess.

What has been said regarding ions consisting of a single atom applies also to ions composed of more than one atom. In a complex ion consisting of many atoms there is a difference between the total number of protons and the total number of electrons held by the particle acting as a whole. When there is an excess of protons in the complex ion, it is positive; when there is an excess of electrons in the complex ion, it is negative. The number of charges on a complex ion

is equal to the difference between the total number of protons and the total number of electrons in the atoms of this ion when considered as a single particle.

Non-Aqueous Ionizations.—The separation of molecules into ions may occur under other conditions than being dissolved in water. Thus ionization of certain substances occurs when these substances are dissolved in liquid ammonia, formic acid, concentrated sulfuric acid, or certain alcohols. When heated to a state of fusion, salts are highly ionized. Molecules of gases may also be ionized by the passage of electric discharges through fields in which they exist. These are special instances of ionizations, other than those occurring in water, which have a theoretical importance, but are not of interest in a course of this kind.

Questions for Study

1. What are electrolytes? Non-electrolytes? Give examples of each.
2. What is ionization? Illustrate with examples.
3. What substances undergo ionization?
4. Why is a solution of an electrolyte electrically neutral?
5. What are the carriers of an electric current through a solution?
6. What is the difference between the sodium atom and the sodium ion? Between the chlorine atom and the chlorine ion?
7. What makes an ion positive? Negative?
8. What is the relationship of valence to the charge upon an ion?
9. Does ionization occur in water only?

UNIT V

ACIDS, BASES, SALTS, HYDROGEN ION CONCENTRATION AND STANDARD SOLUTIONS

CHAPTER XII

ACIDS, BASES AND SALTS

Acids

Name.—The name acid is derived from a Latin word meaning "sour." It was applied to this class of substances because one of the characteristic properties of acids is a sour taste.

Definition.—Before defining an acid it will be helpful to get in mind several facts and illustrations. Acids are electrolytes and will ionize when in solution. The ionization of the more common acids is represented by the following equations:

HCl	$\rightleftarrows$	H^+,	Cl^-
Hydrochloric acid		Hydrogen ion	Chlorine ion
HNO_3	$\rightleftarrows$	H^+,	NO_3^-
Nitric acid		Hydrogen ion	Nitrate ion
H_2SO_4	$\rightleftarrows$	H^+, H^+,	$SO_4^=$
Sulfuric acid		Hydrogen ions	Sulfate ion
H_3PO_4	$\rightleftarrows$	H^+, H^+, H^+,	$PO_4^{\equiv}$
Phosphoric acid		Hydrogen ions	Phosphate ion
$HC_2H_3O_2$	$\rightleftarrows$	H^+,	$C_2H_3O_2^-$
Acetic acid		Hydrogen ion	Acetate ion

Examining the above equations, we find that hydrochloric acid ionizes into hydrogen ions and chlorine ions; nitric acid into hydrogen ions and nitrate ions; sulfuric acid into hydrogen ions and sulfate ions; phosphoric acid into hydrogen ions and phosphate ions; and acetic acid into hydrogen ions and acetate ions. We note at once in these equations that hydrogen ions are common to each of them. This is an important observation, for it represents a fact which applies to all acids: every acid yields hydrogen ions when dissolved in water. Our definition of an acid then is as follows: *An acid is a substance which produces hydrogen ions in excess in solution.* In this definition the conception of the hydrogen "ion" must be stressed, for many substances contain hydrogen but are not acids, because the hydrogen is combined in such a manner that it will not ionize when in solution. For example, ethyl alcohol (C_2H_5OH), glucose ($C_6H_{12}O_6$), ammonium hydroxide (NH_4OH), etc., contain hydrogen, but they do not yield hydrogen ions when placed in solution, and therefore are not acids.

The student should recall that a hydrogen ion is a proton (hydrogen atom minus its electron). Hence an acid may also be defined as a substance which yields protons in solution.

Properties.—Acids may be either solids, liquids, or gases. They manifest their characteristic properties when dissolved in water. This is because the characteristic reactions of acids are produced by hydrogen ions, and if water, which serves as an ionizing agent, is not present, hydrogen ions will not be formed. Since all acids yield hydrogen ions in solution, there are certain properties which are characteristic of acids in general. These properties are as follows:

1. *Acids Have a Sour Taste.*—Everyone is familiar with the sourness of taste that is associated with acids The sour taste of certain fruits and vegetables, such as lemons, oranges, apples, grapefruit, tomatoes, and rhubarb, is due to the presence of acids in these substances.

2. *Acids Change Blue Litmus to Red.*—Litmus is a vegetable dye that is extracted from lichens. It is pink in the

presence of acids and blue in the presence of bases. It is, therefore, used to test for the presence of these substances. Litmus is generally used in the form of litmus paper. Blue litmus paper is prepared by soaking white paper in a solution of the dye to which a little alkali has been added, washing it thoroughly, and then drying and cutting it into small strips. Red litmus paper is made in the same way, except that the paper is treated with an acid solution of litmus before washing and drying.

3. *Acids React With Many Metals, Liberating Hydrogen.* —Some metals are more active in solution than others; that is, they will displace other metals in solutions of their salts. The individual power of each metal to displace other metals has been determined, and upon the basis of this information the metals have been arranged in a series which shows their relative activities. This series is known as the *electromotive or activity series of the metals.* Each metal in this series will displace in a solution all the metals that follow it, and will be displaced by any metal that precedes it. This series is as follows:

ELECTROMOTIVE SERIES OF THE METALS

Potassium
Sodium
Barium
Strontium
Calcium
Magnesium
Aluminum
Manganese
Zinc
Chromium
Iron
Cadmium
Cobalt
Nickel
Tin
Lead
HYDROGEN
Antimony
Bismuth
Arsenic
Copper
Mercury
Silver
Platinum
Gold

The value of the electromotive series in this connection is to show the behavior of hydrogen with respect to other

metals in solution. Hydrogen ions are displaced from solution by the ions of any metal that is above hydrogen in the electromotive series. Therefore, any metal which precedes hydrogen in this list will react with acids and liberate hydrogen, and the ions of all the metals below hydrogen in the series will not displace hydrogen ions from solution; hence these metals will not liberate hydrogen when treated with an acid.

4. *Acids React With Carbonates, Liberating Carbon Dioxide.*—All carbonates are attacked by acids, with the liberation of carbon dioxide. A typical reaction is as follows:

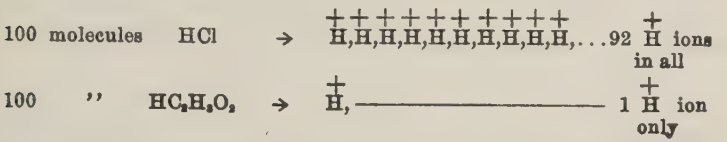
Na_2CO_3	+	H_2SO_4	→	Na_2SO_4	+	H_2O	+	$CO_2\uparrow$
Sodium carbonate		Sulfuric acid		Sodium sulfate				Carbon dioxide

The behavior of acids with carbonates is the basis of the commercial methods for preparing carbon dioxide, which we will study in another chapter.

5. *Unless Very Dilute, Acids Will Attack the Tissues of the Body.*—The stomach and the urinary tract are the only parts of the body that will tolerate acids, the tissues of these parts being adapted to withstand acids, when very dilute. The urine of carnivorous animals is slightly acid, and the normal gastric juice has an acid concentration of about 0.2 to 0.3 per cent hydrochloric acid. The stomach and urinary organs cannot endure higher concentrations of acids, however, and if more than normal amounts of acids get into these parts, by accident or disease, their tissues are attacked with serious consequences.

Strong and Weak Acids.—Some acids manifest acid characteristics in an intense degree and are called strong acids. Other acids exhibit these properties in a mild degree and are considered weak acids. The strength of an acid is dependent upon the number of hydrogen ions it will produce in solution. A strong acid will yield a relatively large number of hydrogen ions in solution; a weak acid will produce a relatively small number of hydrogen ions when dissolved

in water. To illustrate, let us take hydrochloric and acetic acids as examples. Relatively, these acids will yield hydrogen ions as follows:



For every 100 molecules of 0.36 per cent hydrochloric acid in water, 92 molecules will ionize, producing 92 hydrogen ions; for every 100 molecules of acetic acid of the same molecular concentration, only 1 molecule will ionize, liberating 1 hydrogen ion. Thus hydrochloric acid is a strong acid because it yields such a relatively large number of hydrogen ions when placed in water. This acid will dissolve a piece of zinc much more rapidly than acetic acid, it will conduct an electric current much better, and it manifests other acid properties in the same degree of intensity. Other strong acids are nitric and sulfuric. Acetic acid is a weak acid in comparison with hydrochloric acid because it yields so few hydrogen ions when placed in water. Other weak acids are carbonic and boric acids. Carbonic acid (CO_2 in water) is so weak that we drink it with safety and delight at soda fountains, and boric acid is so weak that it can be applied to the eye as an eye wash.

Hypoacidity, Hyperacidity, Acidosis.—As already stated, the concentration of hydrochloric acid in the gastric juice in health is 0.2 to 0.3 per cent. This amount varies in disease, and the conditions known as hypoacidity and hyperacidity often arise. Hypoacidity is a condition in which the gastric juice has less than the normal amount of hydrochloric acid, which is less than 0.2 per cent. In hyperacidity, the hydrochloric acid concentration of the gastric juice is higher than normal, or greater than 0.3 per cent. Acidosis is a condition quite different from those just mentioned, and should not be confused with them. Acidosis is usually the result of an overproduction of acids in the tissues of the body. It occurs in certain diseases, such as

diabetes mellitus. Whether hypo- or hyperacidity exists is determined by an analysis of the gastric juice removed by means of a stomach tube at certain intervals following the ingestion of a test meal. The existence of acidosis is determined by a chemical analysis of the blood.

Bases

Definition.—A base is a compound containing a metal combined with one or more OH groups. Bases are electrolytes and ionize in a manner illustrated by the following equations:

$NaOH$	$\rightleftarrows$	Na^+,	OH^-
Sodium hydroxide		Sodium ion	Hydroxyl ion
KOH	$\rightleftarrows$	K^+,	OH^-
Potassium hydroxide		Potassium ion	Hydroxyl ion
$Ca(OH)_2$	$\rightleftarrows$	Ca^{++},	OH^-, OH^-
Calcium hydroxide		Calcium ion	Hydroxyl ions
NH_4OH	$\rightleftarrows$	NH_4^+,	OH^-
Ammonium hydroxide		Ammonium ion	Hydroxyl ion

In the above examples it will be seen that bases are called hydroxides, and that they dissociate in solution, giving positively charged metallic ions and negatively charged OH groups, the latter being called hydroxyl ions. It will be noted also that hydroxyl ions are common to each example. This observation is typical of every base: all bases contain hydroxyl groups which form hydroxyl ions when dissolved in water. A base may be defined, then, as a *substance which produces hydroxyl ions in excess in solution.* A hydroxyl ion consists of one atom of oxygen and one atom of hydrogen, combined so firmly that they remain together in solution and behave as a single atom with a valence of one when a chemical reaction takes place.

It should be emphasized that a compound containing an OH group is not a base unless it is capable of dissociating in solution and producing hydroxyl "ions." Many substances, notably the alcohols of organic chemistry (e.g., ethyl alcohol, C_2H_5OH), contain OH groups, but are not bases because they do not dissociate and yield hydroxyl ions when in solution.

The terms "base" and "alkali" are synonyms and are used interchangeably. When a compound is said to have alkaline properties, it is equivalent to stating that it is a basic substance.

Properties of Bases.—Most bases are solids. They are soluble in water and do not manifest their characteristic properties except in solution. Since all bases produce hydroxyl ions in solution, upon which their characteristics are dependent, there are certain general properties that are true of all bases. These properties may be summarized as follows:

1. *Bases have a bitter, metallic taste.*
2. *They are slippery, or soapy, to the touch.*
3. *They turn red litmus blue.*
4. *They react with acids to form salts.*
5. *They have a corrosive, disintegrating action upon the tissues of the body.* Hence some bases are referred to as "caustic," e.g., caustic soda, caustic potash.

Strong and Weak Bases.—With bases, strength means dissociating or ionizing power just the same as in the case of acids. A strong base is one that dissociates a relatively large number of hydroxyl ions in solution; a weak base dissociates a relatively small number of hydroxyl ions when dissolved in water. Examples of strong bases are sodium hydroxide and potassium hydroxide. In dilute solutions of these bases, about 90 per cent of the molecules are ionized, yielding hydroxyl ions. Ammonium hydroxide is an example of a weak base. In a dilute solution of ammonium hydroxide, only about 1 per cent of the molecules are ionized. This base is so weak that it may be applied to

clothing as a cleansing agent, or to remove stains, without harming the material to which it is applied. It is obvious that sodium hydroxide could not be put to the same use because it is a much stronger base.

Neutralization.—When acids and bases are mixed together, they react vigorously, and the properties of each disappear. What happens in such a reaction is a combination of the positively charged hydrogen ions of the acid with the negatively charged hydroxyl ions of the base to form neutral un-ionized molecules of water. A typical reaction is as follows:

$$\underset{\text{Sodium hydroxide}}{Na^{+}OH^{-}} + \underset{\text{Hydrochloric acid}}{H^{+}Cl^{-}} \rightarrow \underset{\text{Neutral un-ionized water}}{H_2O} + \underset{\text{Sodium chloride}}{Na^{+}Cl^{-}}$$

In the above reaction the hydroxyl and hydrogen ions combine and form water, which is a neutral un-ionized substance having the properties of neither an acid nor a base. Since the reaction of an acid with a base results in a disappearance of the properties of both, acids and bases are said to neutralize each other, and the process is called neutralization. *Neutralization may be defined as the union of the hydrogen ions of an acid with the hydroxyl ions of a base to form water, a neutral substance.*

Salts

Definition.—*A salt is a product of the reaction of an acid with a base. It is a compound containing the negative ion of an acid combined with the positive ion of a base.*

Preparation.—

1. *Neutralization.*—The simplest method of preparation of salts is by the neutralization of an acid with a base. When an acid is mixed with a base, one of the products formed is water, as we noted, and a second very important product is a salt. The preparation of salts by the interaction of acids with bases is illustrated in Table V.

TABLE V

SALT	METHOD OF FORMATION (NEUTRALIZATION)
KCl Potassium chloride	$K\boxed{OH + H}Cl \longrightarrow H_2O + KCl$
NH_4Cl Ammonium chloride	$NH_4\boxed{OH + H}Cl \longrightarrow H_2O + NH_4Cl$
$MgSO_4$ Magnesium sulfate	$Mg\boxed{(OH)_2 + H_2}SO_4 \longrightarrow 2\,H_2O + MgSO_4$
$Ca(NO_3)_2$ Calcium nitrate	$Ca\boxed{(OH)_2 + 2H}NO_3 \longrightarrow 2\,H_2O + Ca(NO_3)_2$
Na_3PO_4 Sodium phosphate	$3Na\boxed{OH + H_3}PO_4 \longrightarrow 3\,H_2O + Na_3PO_4$

2. *Treatment of an acid with certain metals.*

$$\underset{\text{Zinc}}{Zn} + \underset{\substack{\text{Sulfuric}\\\text{acid}}}{H_2SO_4} \rightarrow \underset{\substack{\text{Zinc}\\\text{sulfate}}}{ZnSO_4} + H_2\uparrow$$

Normal Salt—Acid Salt—Basic Salt.—A *normal salt* is a product of complete neutralization. It does not contain replaceable hydrogen or hydroxyl ions. Thus sodium chloride (NaCl), potassium sulfate (K_2SO_4), and sodium phosphate (Na_3PO_4) are normal salts. However, acids and bases may be mixed in unequal quantities, in which event the resulting products are not completely neutralized. In this manner an acid salt or a basic salt may be formed. An *acid salt* is one that contains replaceable hydrogen in its molecule. For example, potassium hydrogen sulfate ($KHSO_4$) and sodium di-hydrogen phosphate (NaH_2PO_4) are acid salts. Each of these compounds contains replaceable hydrogen that forms hydrogen ions in solution and gives the litmus test for an acid when dissolved in water. A *basic salt* is one that contains hydroxyl groups and yields hydroxyl ions when dissolved in water. Basic lead nitrate ($Pb(OH)NO_3$) is an example of a basic salt.

Antidotes for Wounds Produced by Acid or Base.—The chemical principle that is used in treating a wound caused by an acid or a base is neutralization. Acids and bases are natural antidotes for each other because each neutralizes the corrosive constituents of the other. Hence the most logical treatment for a burn produced by an acid is to wash with water and apply a solution of a weak base. The water will dilute and wash away the acid to an extent, but is insufficient as a treatment, and is suggested because water can usually be obtained more quickly than any other remedy, and quick action is important when an accident occurs. The treatment with water is followed as quickly as possible by the application of a solution of a weak base, the most satisfactory of which is sodium bicarbonate. In case this substance is not available, limewater or dilute ammonia may be used.

The same principles hold good for the treatment of a burn caused by a basic substance. A wound produced by a base should be washed with water and a dilute solution of a weak acid, like acetic acid, should be applied as quickly as possible.

The following rules for treatment of wounds produced by acids or bases should be memorized:

For an acid burn, apply water and a dilute solution of either sodium bicarbonate, ammonia, or limewater. In case none of these remedies is available, any weak base may be used. Stronger bases may be used also *if greatly diluted.*

For a burn produced by a base, apply water and very dilute acetic acid, or saturated boric acid. In case these acids are not available, any weak acid may be used; also strong acids, *if greatly diluted.*

The same chemical principles enter into the treatment of hyperacidity and hypoacidity. For hyperacidity, sodium bicarbonate (baking soda) or magnesium hydroxide ("milk of magnesia") solutions are used because these substances are bases and will neutralize acidity. Furthermore, they are weak bases and will not harm the tissue as strong bases would. Since hypoacidity is a deficiency of hydrochloric acid

in the gastric juice, one remedy for this condition is to give very dilute hydrochloric acid by mouth.

Questions for Study

1. Define an acid.
2. Give five general properties of acids.
3. Distinguish between strong and weak acids. Give examples of each.
4. What is hypoacidity? Hyperacidity? Acidosis?
5. What is a base?
6. Give 5 general properties of bases.
7. Distinguish between strong and weak bases. Give an example of each.
8. What is neutralization?
9. What is a salt?
10. How are salts prepared?
11. What would you do in case of an acid burn?
12. How would you proceed to treat a wound produced by a basic substance?
13. What remedies are used for hyperacidity? For hypoacidity? Why?

CHAPTER XIII

pH AND STANDARD SOLUTIONS

pH—Definition and Explanation.—The designation pH is an abbreviated expression for denoting the hydrogen-ion concentration of a solution. It was proposed by the chemist Sörensen. In the Sörensen scale, pH values range from 0 to 14. A pH of 7 means a neutral solution. *At any pH value below 7 the solution is acid, and the lower the value, the greater is the hydrogen-ion concentration. At any pH value above 7 the solution is basic, and the higher the value, the greater is the hydroxyl-ion concentration.*

Before attempting to explain pH we must first get an idea of the use of logarithms. A logarithm is an algebraic exponent applied to a certain base. In pH work the base used is 10. In the following mathematical deductions

$$10^1 = 10$$
$$10^2 = 100$$
$$10^3 = 1{,}000$$
$$10^4 = 10{,}000$$
$$10^5 = 100{,}000$$

the superscripts, 1, 2, 3, 4, 5, are logarithms. They show how many times 10 has served as a multiplier in calculating the total value of the abbreviated expression. In mathematics logarithms are used for their great convenience in calculating and in expressing large numbers. Thus in the above series of numbers, 100,000 is simply $10 \times 10 \times 10 \times 10 \times 10$, or 10 raised to the fifth power. Instead of writing this number as 10 followed by four zeros, we can more conveniently use the abbreviated expression 10^5. Similarly, we may express larger numbers in an abbreviated manner by using a logarithm applied to the base 10, and obviously, the greater the number, the more convenient is this system.

In attempting to understand the meaning of pH, let us first take an example of our problem. Suppose that we

want to say that there is one one-hundred thousandth of a gram of H ions in one liter of solution. We might express this idea thus:

$\frac{1}{100{,}000}$ gram of H ions in 1 liter of solution, or

$\frac{1}{10^5}$ gram of H ions in 1 liter of solution

or we can do away with the fraction by bringing the denominator 10^5 into the numerator and simply changing the sign of the exponent 5. We will then have the expression:

10^{-5} gram H ions in one liter of solution

Now, instead of writing all this out, why not be brief and use the logarithm, –5, only? This is exactly what Sörensen did when he proposed the pH system. By definition it was

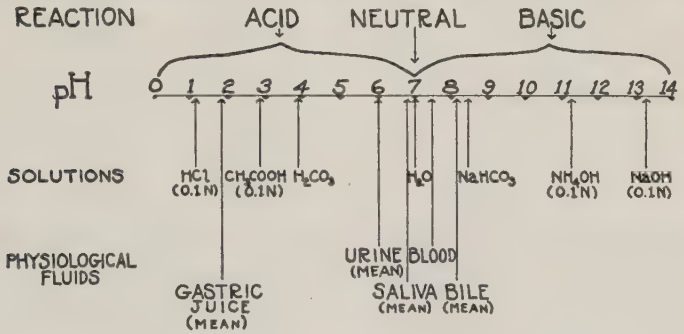


Fig. 26.—A diagrammatic representation of the pH system.

agreed that *pH is the negative logarithm of the base 10 used to designate the grams of hydrogen ions in one liter of a solution.* For our illustrative solution then, we designate the hydrogen-ion concentration by simply saying that it has a pH of 5. In doing this we must remember that *pH always means a negative logarithm, it always applies to the base 10, and it specifically indicates the grams of hydrogen ions in one liter of solution.*

We may illustrate further the meaning of pH by considering its application to water. In one liter of water there is one ten-millionth of a gram of H ions. Now,

$$\frac{1}{10{,}000{,}000} = \frac{1}{10^7} = 10^{-7}$$

Therefore, the pH of water is 7. But water is a neutral substance. When a molecule of water ionizes

$$H_2O \rightarrow H^+, OH^-$$

there are as many OH ions formed as H ions. Hence the amount of OH ions in 1 liter of water is the OH equivalent of 10^{-7} grams of H ions. Therefore the pOH of water is 7. Thus at pH 7, the pOH is 7; hence it becomes clear why pH 7 represents a neutral point on the Sörensen scale.

In the beginning of our discussion we stated that at any pH below 7 the solution is acid and at any pH above 7 the solution is basic. We may prove this by selecting points on the pH scale and calculating the relative concentrations of H and OH ions. Let us take pH 4 as an example.

pH 4 means 10^{-4} gram of H ions in 1 liter of solution, or

$\frac{1}{10^4}$ gram of H ions in 1 liter of solution, or

$\frac{1}{10{,}000}$ gram of H ions in 1 liter of solution

The entire pH scale goes up to 14. Therefore, the pOH concentration on this scale is obtained by subtracting the pH value from 14. Thus, at pH 4, the pOH is 10 (14 – 4 = 10), and

$$10^{-10} = \frac{1}{10^{10}} = \frac{1}{10{,}000{,}000{,}000}$$

We know that $\frac{1}{10{,}000}$ gram of H ions is much greater than the OH equivalent of $\frac{1}{10{,}000{,}000{,}000}$ of a gram, because the smaller the denominator of a fraction, the greater is the value of that fraction. Actually the solution contains one million more H than OH ions and is therefore acid.

In a similar way we may calculate the pH of any point on the scale and show that at any point below pH 7 there are more H than OH ions and at any point above pH 7 there

are more OH than H ions. In other words, calculation will show that all values on the Sörensen scale below pH 7 are acid and all values above pH 7 are basic.

The importance of pH becomes apparent when we begin to think of physiologic substances. Thus the pH of normal human urine ranges from 5.0 to 7.0, and that of normal gastric juice is 1.3 to 2.5; these are examples of physiologic fluids that are acid. The pH of saliva ranges from 6.0 to 7.9. Saliva is a substance whose reaction is close to the neutral point. Normal blood has a pH around 7.35; hence it is very slightly basic. A more basic body fluid is the bile which has a pH of 7.8 to 8.6.

Standard Solutions.—A standard solution is one whose concentration is established by definition. Two kinds of standard solutions, the molar and the normal solution, are in universal use. Such solutions are a great convenience to the chemist. They aid him in analytical and experimental work in his own laboratory and enable him to express the results of his analyses or experiments in uniform and convenient terms.

The Molar Solution.—*A molar solution contains one gram molecular weight of solute in one liter of solution.* A gram molecular weight of solute is simply the number of grams of the substance that corresponds to its molecular weight. This quantity is also called a gram mole.

To prepare a molar solution one first finds out the molecular weight of the solute and weighs out the amount of this substance in grams that corresponds to its molecular weight. This amount of the substance is placed in a liter flask, solvent is added and the mixture is shaken until all of the solute is dissolved. Solvent is then added until it reaches the one liter mark on the neck of the flask. After thorough mixing, one obtains a solution containing one gram molecular weight of solute in one liter of solution, or a molar solution.

To illustrate, let us consider the preparation of molar solutions of glucose ($C_6H_{12}O_6$) and sodium chloride (NaCl).

For glucose, $C_6H_{12}O_6$:

Atomic weight of	6 C	= 72.00
Atomic weight of	12 H	= 12.09
Atomic weight of	6 O	= 96.00
Molecular weight of	$C_6H_{12}O_6$	= 180.09

For sodium chloride, NaCl:

Atomic weight of	Na	= 23.00
Atomic weight of	Cl	= 35.45
Molecular weight of	NaCl	= 58.45

To make a molar solution of glucose, one dissolves 180.09 grams of glucose in a small amount of the desired solvent and then adds more solvent until the solution reaches a volume of exactly one liter. To prepare a molar solution of sodium chloride, one follows the same procedure, placing 58.45 grams of NaCl in one liter of solution.

The Normal Solution.—Molar solutions are useful and satisfactory for quantitative work with non-electrolytes, or substances that do not ionize in solution. But to work with electrolytes, the chemist needs a solution that may be used to study quantitative relationships between ions. Hence, another standard solution, namely, the normal solution, was established.

A normal solution contains one gram equivalent weight of solute in one liter of solution. In an equivalent weight of a compound there is one combining weight of cation, also one combining weight of anion. Thus in the normal solution there is one combining weight of cation and the same quantity of anion.

If a normal solution of an acid is to be prepared, the calculation is made in terms of the ionizable hydrogen. Thus *a normal solution of an acid contains 1.008 grams of ionizable hydrogen in one liter of solution.* It will be recalled that 1.008 is the combining weight of hydrogen (see page 40). This weight of ionizable hydrogen in grams is present in a gram equivalent weight of any acid. Hence a normal solution of one acid is equivalent in content of ionizable hydrogen to a normal solution of any other acid.

To illustrate, let us consider the preparation of normal solutions of hydrochloric, sulfuric, and phosphoric acids. First, we will calculate the molecular weights.

Hydrochloric acid, HCl
Atomic weight of H = 1.008
Atomic weight of Cl = 35.45
Molecular weight of HCl = 36.458

Sulfuric acid, H_2SO_4
Atomic weight of 2 H = 2.016
Atomic weight of S = 32.060
Atomic weight of 4 O = 64.000
Molecular weight of H_2SO_4 = 98.076

Phosphoric acid, H_3PO_4
Atomic weight of 3 H = 3.024
Atomic weight of P = 31.020
Atomic weight of 4 O = 64.000
Molecular weight of H_3PO_4 = 98.044

To prepare a normal solution of hydrochloric acid, one uses chemical techniques by which 36.458 grams of HCl are dissolved in a small amount of appropriate solvent and the volume is made up to exactly one liter by adding more solvent. 36.458 grams, the molecular weight of HCl, is also a gram equivalent weight of this acid; in this quantity there is present 1.008 grams of ionizable hydrogen.

The molecular weight of H_2SO_4 is not the same as its equivalent weight. There are two replaceable hydrogen ions in H_2SO_4, hence to get an equivalent weight of this acid, we divide the molecular weight by 2. Therefore, to prepare a normal solution of H_2SO_4, we use chemical methods by which $\frac{98.076}{2}$, or 49.038, grams of H_2SO_4 are dissolved in a small amount of appropriate solvent and more solvent is added carefully until a volume of exactly one liter of solution is obtained. One liter of such a solution will contain 1.008 grams of ionizable hydrogen.

To obtain an equivalent weight of H_3PO_4, one divides the molecular weight by 3. This is necessary because there are three replaceable hydrogen ions in the H_3PO_4 molecule. Thus, to prepare a normal solution of H_3PO_4 one uses

chemical procedures by which $\frac{98.044}{3}$, or 32.681, grams of H_3PO_4 are dissolved in exactly one liter of solution. Such a solution will contain 1.008 grams of ionizable hydrogen in one liter.

If a normal solution of a base is to be prepared, the calculation is made in terms of ionizable hydroxyl. Thus, *a normal solution of a base contains 17.008 grams of ionizable hydroxyl in one liter of solution.* It will be recalled that 17.008 grams of hydroxyl ions will combine with 1.008 grams of hydrogen ions to form 18.016 grams of H_2O, hence this amount is one combining weight of hydroxyl and it is the quantity that is present in a gram equivalent weight of any base. Hence all normal solutions of bases are equivalent in concentration of ionizable hydroxyl.

To illustrate, let us consider the preparation of normal solutions of sodium hydroxide and calcium hydroxide. We will first calculate the molecular weights as follows:

Sodium hydroxide, NaOH	
Atomic weight of Na	= 23.00
Atomic weight of O	= 16.00
Atomic weight of H	= 1.008
Molecular weight of NaOH	= 40.008
Calcium hydroxide, $Ca(OH)_2$	
Atomic weight of Ca	= 40.08
Atomic weight of 2 O	= 32.00
Atomic weight of 2 H	= 2.016
Molecular weight of $Ca(OH)_2$	= 74.096

As there is only one hydroxyl in the NaOH molecule, the equivalent weight of NaOH is the same as its molecular weight. Therefore, to prepare a normal solution of NaOH, one uses chemical techniques by which 40.008 grams are dissolved in exactly one liter of solution. In such a solution there are 17.008 grams of ionizable hydroxyl in one liter.

Calcium hydroxide is a base which contains two hydroxyl groups in the molecule. Therefore, to get an equivalent weight of $Ca(OH)_2$ one divides the molecular weight by 2: this gives a quantity containing 17.008 grams of hydroxyl, which, by definition, is the amount that is present in one liter of a normal solution of a base. Therefore, to prepare a

normal solution of $Ca(OH)_2$, one dissolves $\frac{74.096}{2}$, or 37.048, grams of $Ca(OH)_2$ in one liter of solution.

To prepare a normal solution of a salt that is to be used as an electrolyte, one first derives the molecular weight and then calculates the equivalent weight. It should be kept in mind that an equivalent weight of a salt contains one combining weight of cation and the same amount of anion. We may, therefore, make our deductions in terms of either the cation or the anion of the salt.

To illustrate, let us consider the preparation of normal solutions of calcium chloride and trisodium phosphate. We will first derive the molecular weights of these salts.

Calcium chloride, $CaCl_2$		
Atomic weight of Ca	=	40.08
Atomic weight of 2 Cl	=	70.90
Molecular weight of $CaCl_2$	=	110.98
Trisodium phosphate, Na_3PO_4		
Atomic weight of 3 Na	=	69.00
Atomic weight of P	=	31.02
Atomic weight of 4 O	=	64.00
Molecular weight of Na_3PO_4	=	164.02

The combining weight of calcium is 20; it is equal to the atomic weight, 40, divided by the valence, 2. Hence to calculate an equivalent weight of $CaCl_2$ (which must contain one combining weight of calcium or of chloride), one divides the molecular weight of $CaCl_2$ by 2. Therefore, to prepare a normal solution of calcium chloride, one places $\frac{110.98}{2}$, or 55.49, grams of this salt in the desired solvent and makes the solution up to a volume of exactly one liter. In such a solution, there is one combining weight of dissociable calcium or chloride ions.

To derive the equivalent weight of Na_3PO_4, one divides the molecular weight by 3 as there are three replaceable sodium ions in the Na_3PO_4 molecule. To prepare a normal solution of Na_3PO_4, one dissolves $\frac{164.02}{3}$, or 54.67, grams of this salt in appropriate solvent and makes the solution up to a volume of exactly one liter. In such a solution there is

one combining weight of replaceable sodium ion, also the same quantity of phosphate ion.

The investigator may dilute a normal solution 10 times, or 100 times, or 1,000 times, etc., and thus obtain a solution that is one-tenth normal (0.1 N), or one-hundredth normal (0.01 N), or one-thousandth normal (0.001 N), respectively; similarly, he may prepare solutions that are one-tenth molar (0.1 M), or one-hundredth molar (0.01 M), or one-thousandth molar (0.001 M), and so on, by diluting the molar solution 10, or 100, or 1,000 times. The concentration of the standard solution that is selected is based upon the nature of the work that is to be done; the more sensitive the measurement to be made the greater is the dilution used.

Questions for Study

1. Define pH.
2. At what pH values is a solution acid? Basic?
3. At what pH is a solution neutral?
4. What is a molar solution? In principle how is a molar solution prepared?
5. What is a normal solution? In principle how is a normal solution prepared?
6. Discuss the purpose and applications of the molar solution.
7. Discuss the purpose and applications of the normal solution.

UNIT VI

NITROGEN AND THE ATMOSPHERE

CHAPTER XIV

NITROGEN

Occurrence.—Nitrogen occurs in both the free and the combined states. As the free element, it constitutes about four-fifths of the atmosphere by volume. In the form of nitrogen compounds, it exists in the soil in small quantities, and in great abundance in certain natural deposits, such as the sodium nitrate ("nitre") beds of Peru and Chile. Nitrogen is also a constituent of the proteins, a very important class of compounds which make up a large part of the tissues of animals and plants.

Preparation.—

1. *From the Air.* (a) *By Absorption of Oxygen.*—The air is essentially a mixture of nitrogen and oxygen. Nitrogen may, therefore, be prepared from air by removing the oxygen. This is accomplished by placing some substance that will combine with oxygen, like phosphorus, copper, or iron, in a closed vessel of air. If phosphorus is used, it combines with the oxygen present to form phosphorus pentoxide, a solid, and in this manner oxygen is removed from the presence of the nitrogen of air. This preparation is represented by the following scheme:

$$\text{Air}\begin{cases}O_2\\N_2\\\text{Other gases}\end{cases} + P \rightarrow \underset{\text{Phosphorus pentoxide}}{P_2O_5} + \underset{\text{Nitrogen}}{N_2} + \text{Other gases}$$

The "other gases" exist in the air in small quantities, and hence nitrogen prepared by this method is not pure.

Copper or iron will also remove oxygen from the air by forming oxides, and may be used to prepare impure nitrogen.

(b) *Evaporation of Liquid Air.*—A second method of separating the nitrogen and oxygen of the air is by the evaporation of liquid air. This is the commercial method of preparing both nitrogen and oxygen. The boiling point of liquid nitrogen is –196° C.; that of liquid oxygen is –183° C. When liquid air is allowed to evaporate, the nitrogen passes off first, since there is a difference of 13 degrees in the boiling points of nitrogen and oxygen. In this manner nitrogen may be separated from oxygen. Oxygen and nitrogen may be prepared more inexpensively by this method than by any other process.

2. *By Heating Ammonium Nitrite.*—Pure nitrogen is prepared by decomposing nitrogen compounds. The simplest procedure for obtaining nitrogen in a very pure form is heating ammonium nitrite. Ammonium nitrite is a white solid; when gently heated it decomposes, yielding nitrogen and water.

$$\underset{\text{Ammonium nitrite}}{NH_4NO_2} + \text{heat} \rightarrow \underset{\text{Water}}{2\,H_2O} + \underset{\text{Nitrogen}}{N_2}$$

The nitrogen evolved is collected by displacement of water.

Properties.—Nitrogen is a colorless, odorless, and tasteless gas. It is slightly lighter than air and is 14 times heavier than hydrogen (atomic weight = 14). It is slightly soluble in water. Under great pressure and at very low temperatures, nitrogen gas may be converted into liquid nitrogen, and at still lower temperatures liquid nitrogen becomes a snowlike solid. Liquid nitrogen boils, i.e., becomes a gas, at –196° C.

The most outstanding chemical property of nitrogen is its inactivity. All matter on the surface of the earth is exposed to nitrogen constantly, since this gas composes four-fifths of the atmosphere, but no reactions between this element and other substances occur under ordinary conditions of temperature and pressure. If the temperature is increased, however, nitrogen will combine with other substances, notably oxygen, hydrogen, magnesium, aluminum, and calcium carbide.

Uses of Nitrogen.—

1. *In Electric Light Bulbs.*—The inactivity of nitrogen makes it valuable for several commercial purposes. One of these is to fill electric light bulbs. If an incandescent electric light bulb were filled with air, the tungsten filament would "burn out" as soon as the electric current began to flow through the wire, because air contains oxygen which would support the combustion of tungsten. A bulb filled with nitrogen, however, glows brightly when the current is turned on, and the tungsten filament is not attacked by the nitrogen.

2. *Filling Thermometers.*—A second application of nitrogen, based upon its inactivity, is in the manufacture of mercury thermometers, which are used to measure high temperatures. When mercury is heated to high temperatures, it volatilizes, and hence thermometers used to measure elevated temperatures must be filled with some gas under pressure to prevent this volatilization. Nitrogen does not combine with mercury and is, therefore, valuable for the construction of thermometers of this type.

3. *Diluent of Oxygen.*—Another use of nitrogen is in a negative capacity. This element, constituting 80 per cent of the air, dilutes the oxygen used for combustions and, in this manner, slows down burning processes to a degree that is more desirable for our purposes. If the air were composed of oxygen alone, the iron of a stove or furnace would burn the same as wood or coal, and all combustions would take place too rapidly to suit our convenience. It has also been shown that breathing pure oxygen continuously is injurious to animals, causing irritation and congestion of the lungs, hence the nitrogen of the air serves an important function in diluting the oxygen used for respiration.

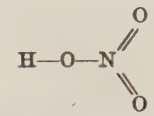
4. *Plant Food.*—One of the great functions of nitrogen in nature is to supply an essential constituent of the food of plants, which in turn produce food for animals. Plants require nitrogen for their growth and for the production of protein foods which they store in their tissues, but the nitrogen which they use must be in the form of nitrates, or

compounds which can be converted into nitrates by bacterial action, e.g., nitrites and ammonia. These compounds are supplied to the soil naturally by the decay of animal and vegetable matter and by nitrogen-fixing bacteria, and artificially by the application of fertilizers. We will discuss this process more fully in a succeeding paragraph upon nitrogen fixation.

Nitric Acid

HNO_3

Molecular formula



Structural formula

Preparation.—Nitric acid is prepared by distilling a mixture of sodium nitrate and sulfuric acid.

$2\ NaNO_3$	+	H_2SO_4	→	Na_2SO_4	+	$2\ HNO_3$
Sodium nitrate		Sulfuric acid		Sodium sulfate		Nitric acid

Properties.—Pure nitric acid is a colorless liquid. It is an unstable compound, decomposing under the influence of light and when heated mildly. When nitric acid decomposes, it yields a brown colored gas, nitrogen dioxide (NO_2); hence a bottle of nitric acid which has been exposed to light has a brown color, due to the presence of this gas. Nitric acid has the typical properties of a strong acid, and is also a powerful oxidizing agent. It does not yield hydrogen when mixed with metals because the hydrogen when displaced by a metal is immediately oxidized by the nitric acid, forming water.

Uses.—Nitric acid is used in the preparation of explosives. Nitroglycerine (dynamite), nitrocellulose (smokeless powder), picric acid, trinitrotoluol (T.N.T.) are highly explosive compounds, whose explosive nature is due to the presence of nitro (NO_2) groups from nitric acid. Black gunpowder (smoke-producing powder) is a mixture of sulfur, charcoal, and potassium nitrate, a salt of nitric acid. Nitric acid is also used in the manufacture of plastics, such as celluloid; and in the preparation of dyes and drugs.

Nitrates, or the salts of nitric acid, must be present in the soil to promote the growth of plants, and they are therefore indispensable as fertilizers. Nitrogen has truly been called a "preserver and destroyer of life" by one author[1] because of the use of nitrogen in the preparation of compounds which may be used as explosives to destroy life, or as drugs to save life, or as fertilizers for the growth of plants that yield food for man.

Ammonia and Ammonium Hydroxide

Ammonia—NH_3.—Ammonia is a colorless gas, with a sharp, suffocating odor. It is a little more than one-half as heavy as air. It is very soluble in water, one volume of water dissolving about 700 volumes of ammonia. It is easily liquefied by applying pressure at ordinary temperatures, and, when liquid ammonia is allowed to evaporate, it absorbs a great deal of heat; hence ammonia is used in the manufacture of ice and for refrigeration purposes. Ammonia is prepared on a commercial scale in this country as a by-product in the production of illuminating gas from coal. Coal contains a small amount of ammonia combined with other elements, and if heated in the absence of air, the ammonia is evolved and may be collected by passing it into water or sulfuric acid. Ammonia may also be prepared by direct combination of nitrogen with hydrogen at increased temperature and pressure, a process which will be described under nitrogen fixation. Ammonia is one of the products liberated by the action of putrefactive bacteria upon nitrogenous organic matter.

Ammonium Hydroxide—NH_4OH.—When ammonia is dissolved in water, a new compound, ammonium hydroxide, is formed.

$$\underset{\text{Ammonia}}{NH_3} + \underset{\text{Water}}{H_2O} \rightleftarrows \underset{\text{Ammonium hydroxide}}{NH_4OH}$$

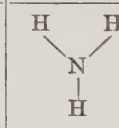
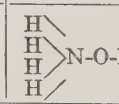
In the above reaction the valence of nitrogen changes from 3 to 5. The radical consisting of nitrogen and four atoms of hydrogen behaves as a univalent metal, and is given the name ammonium.

[1]Slosson, E. E.: Creative Chemistry, New York, 1919, The Century Co.

Ammonium hydroxide is a weak base. Its solutions turn red litmus blue and manifest all the properties of a base, but in a mild degree. It is an unstable compound, decomposing readily into ammonia and water, the products from which it is formed. The above equation showing its formation is, therefore, written with the arrows pointing in both directions. When ammonia gas is passed into water, ammonium hydroxide is formed, and if the vessel containing the latter is kept closed, the compound will not decompose. If, however, a vessel containing ammonium hydroxide is left open, ammonia gas will pass off into the air and only water will remain after a time. The latter change may be effected more quickly by boiling the solution. "Household ammonia" and "aqua ammoniae" are dilute solutions of ammonia in water. They are used for cleaning and for softening water.

The relations between ammonia and ammonium hydroxide are summarized in Table VI.

TABLE VI

NAME	MOLECULAR FORMULA	STRUCTURAL FORMULA	PHYSICAL STATE	PREPARATION
AmmonIA	NH_3		Gas	From coal and by direct combination of nitrogen and hydrogen
AmmonIUM hydroxide	NH_4OH		Liquid	From ammonia and water

Fixation of Nitrogen.—Previous to 1913 the nations of the world depended largely upon the nitrate deposits of Chile to supply them with their necessary nitrogen compounds. This supply is rapidly approaching exhaustion. The only other great source of nitrogen is the free nitrogen of the atmosphere. The nitrogen of the air is an inexhaustible supply, but, being in the free, molecular state, it is not utilizable by

animals, nor by most plants. Nitrogen must be in the form of compounds, such as nitrates, nitrites, or ammonia, to be utilized by plants, and in the form of proteins to be used by animals. Atmospheric nitrogen is now being converted into nitrogen compounds upon a successful commercial basis by a process known as the fixation of nitrogen. There are several methods of nitrogen fixation in use at the present time, the most important of which we will describe.

1. *Fixation as Ammonia.*—The most successful method of nitrogen fixation is the Haber process, originated in Germany. The Haber process consists essentially of combining nitrogen with hydrogen under great pressure at moderately elevated temperatures in the presence of uranium, or iron, which act as catalysts, or promoters of the reaction. By this process ammonia is formed:

N_2	+	$3\ H_2$	→	$2\ NH_3$
Nitrogen		Hydrogen		Ammonia

The nitrogen used in this process is prepared by the liquid-air method already described. The hydrogen is obtained by the electrolysis of water.

2. *The Electric Arc Method.*—A second nitrogen-fixing process is the direct combination of nitrogen with oxygen in an electric arc. When an electric discharge is passed through air, great heat is generated, since the air is a poor conductor of electricity, and the result of this liberation of energy is a splitting of molecules of nitrogen and oxygen into their atoms. The atoms of nitrogen and oxygen combine to form nitrogen oxides. These oxides are dissolved in water and finally oxidized to nitric acid, which is the most utilizable of all the compounds of nitrogen. The electric arc method is not a commercial success at the present time. The method is of theoretical interest in that it illustrates how Nature provides the soil with small amounts of nitrates produced by means of lightning during electric storms.

3. *Fixation by Nitrifying Bacteria.*—A few plants have the power of nitrogen fixation. These belong to the family of pod-bearing plants called the legumes, such as cow peas,

soybeans, vetch, clover, alfalfa, etc. Leguminous plants have small nodules upon their roots called tubercles (see Fig. 27), which contain bacteria that have the remarkable power of combining the nitrogen of the air with oxygen to form nitrates. Such plants do not require a nitrogenous soil, or nitrogen fertilizers, as they are capable of taking

Fig. 27.—Roots of a cowpea plant showing nodules in which nitrogen-fixing bacteria live. (From Bulletin No. 179, the University of Illinois College of Agriculture.)

from the air all the nitrogen they need. The practical importance of this group of plants is that they use part of the nitrates, which they have produced, for the synthesis of proteins, and the remaining nitrates are left in the soil. The latter enrich the soil to a considerable extent and, if the leguminous crop is not removed, it ultimately falls upon the ground, decays, and adds more utilizable nitrogen to the soil. *The great value of leguminous plants is that they*

enrich the soil with nitrogen compounds which they prepare from the nitrogen of the air. Farmers have for a long time taken advantage of this property of the leguminous plants and have realized that to grow such crops may be more beneficial to the soil than applying nitrogen compounds as fertilizers.

The Nitrogen Cycle.—We have previously shown that nitrogen must be in the form of nitrates to be utilized by plants, and that nitrates are introduced into the soil as fertilizers and through the activity of leguminous plants. We will now trace the course of this element through Nature,

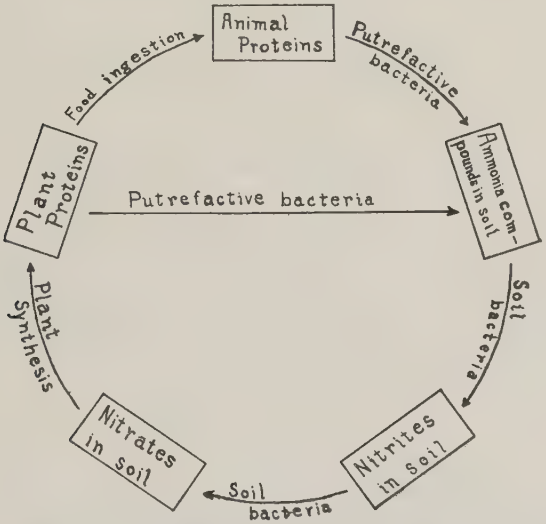


Fig. 28.—Diagrammatic scheme showing the nitrogen cycle in Nature.

taking nitrates as our starting point. Plants absorb nitrates from the soil through their roots and convert them into proteins. Proteins are eaten by animals as food and become a part of the bodies of animals for a time. Animals utilize the proteins for their life processes and return protein decomposition products to the soil as waste from their bodies; protein nitrogen is also returned to the soil by animals when they die, through the decay of their bodies. The nitrogenous substances in the waste products and decaying tissues of animals finally become ammonia and ammonium

compounds through the activity of putrefactive bacteria. From this point the process is carried on by two different strains of bacteria. One group of organisms converts ammonium compounds into nitrites, and a second type of bacteria converts nitrites into nitrates, which is our starting point. The element nitrogen thus passes through a complete cycle in Nature. This is illustrated by the diagram of Fig. 28. Not all proteins produced by plants are eaten by animals. A large part falls upon the earth when plants die and is converted into ammonia by putrefactive bacteria, just as the tissues of dead animals are decomposed with the production of this compound. In this case our cycle does not include animals and passes directly from the stage of "Plant proteins" to that of "Ammonia compounds in soil," as indicated in the diagram.

Certain natural chemical processes take place in the soil which release free nitrogen to the air again. In this manner nitrogen transferred from the atmosphere to the soil by nitrogen-fixation processes, and to a large extent utilized by plants and animals for a time, is returned to the atmosphere again. Thus there is a continuous exchange of nitrogen between the air and the soil.

Questions for Study

1. Relate the occurrence of nitrogen.
2. Describe three methods of preparing nitrogen.
3. Give the physical and chemical properties of nitrogen.
4. What are the uses of nitrogen?
5. What are the properties of nitric acid?
6. Mention several uses of nitric acid.
7. What is ammonia? Ammonium hydroxide? What are the properties of each?
8. What are the uses of ammonia? Of ammonium hydroxide?
9. What is meant by nitrogen fixation?
10. Describe one commercial method of nitrogen fixation.
11. Describe the fixation of nitrogen by means of leguminous plants. What is the importance of this process?
12. Give the nitrogen cycle of Nature.

CHAPTER XV

THE ATMOSPHERE

The great volume of gases which envelops the earth is called the atmosphere. It is more often referred to as the air. To us the atmosphere does not seem to have weight, since it is composed of gases whose pressure is balanced in all directions, but at sea level it has a pressure equivalent to a weight of 14.7 pounds per square inch of surface. This is known as the pressure of 1 *atmosphere*, and is sufficient to balance a column of mercury 76 centimeters in height and 1 square centimeter in cross section.

The air is a physical mixture of gases. It has approximately the composition shown by the following table:

Constituent	Per Cent by Volume
Nitrogen	78.00
Oxygen	21.00
Argon	0.94
Carbon dioxide	0.03
Water vapor	Variable
Helium	Trace
Neon	Trace
Krypton	Trace
Xenon	Trace

In addition to the above constituents, there may be found ammonia, hydrogen sulfide, sulfur dioxide, ozone, or carbon monoxide. The existence of the latter substances in the air is determined by local conditions. For instance, ammonia and hydrogen sulfide would be found in air that has been in contact with decaying organic matter; sulfur dioxide in a region of burning sulfur, e.g., near volcanoes, or furnaces which smelt ores containing sulfur; and carbon monoxide in the vicinity of incompletely burning carbon, such as near poorly ventilated stoves or furnaces, or in regions of traffic congestion where there is much spent gas from automobiles. Dust particles, consisting of mineral and organic matter, also exist in the air in varying amounts.

Functions of the Chief Constituents of Air.—

1. Oxygen is essential for the burning of fuels; the decay of organic debris; the oxidation of foods, and other chemical reactions in the human body and the body of animals; and the vital processes of plants.

2. Nitrogen dilutes the oxygen of the air, and in this manner makes the various oxidation processes take place at a slower and more desirable rate. It is also a potential means of enriching the soil in being a source of nitrogen compounds, which are produced by nitrifying bacteria upon the roots of leguminous plants.

3. Carbon dioxide is used by plants in the production of carbohydrates.

4. Water vapor is the form in which water is conveyed from the sea to the land for the maintenance of plant and animal life. It also prevents excessive evaporation from plants, and adds greatly to the comfort of animals, if present in favorable amounts, by aiding in the proper dissipation of heat from their body surfaces.

5. Dust particles serve as nuclei for the condensation of water vapor, and are, therefore, necessary for the precipitation of water vapor as rain. They also enhance the natural beauty of the sky by refraction and reflection of light.

The Helium Family.—The chemistry of oxygen, nitrogen, and water has been developed, and that of carbon dioxide will be considered later. It remains to discuss briefly the other constituents of air. Argon, helium, neon, krypton, and xenon are called the rare gases because they occur in such small quantities. They are very inactive chemically, combining with no elements as far as is known. Their valence is, therefore, zero. Argon received its name from a Greek word meaning "lazy," because it was found to be such an inactive element. Helium was found to be a constituent of the sun before its existence upon the earth was known, hence its name from the Greek word "helios," meaning the sun. This discovery was made by means of the spectroscope, an instrument which reveals the pres-

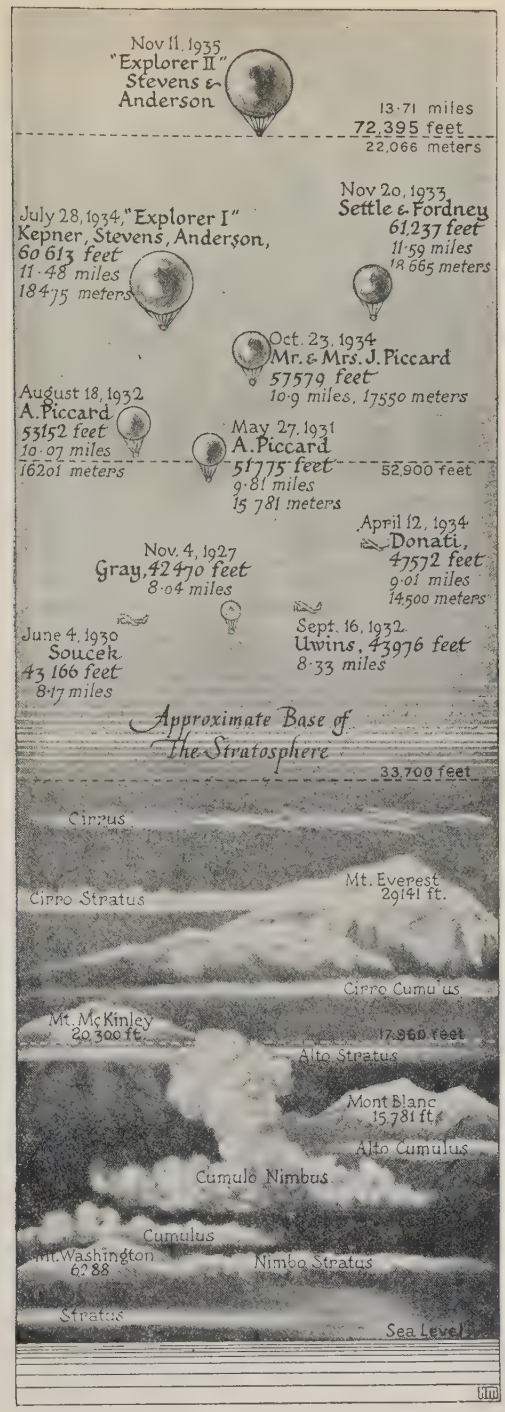


Fig. 29.—Diagrammatic representation of the atmosphere showing the greatest heights man has reached. Shading is used arbitrarily to indicate density of the atmosphere, greatest near sea level and growing less upward. (Courtesy of the National Geographic Magazine 69: 694, 1936.)

ence of substances by the way the light from their flames passes through a glass prism. Sunlight shows a spectroscopic picture identical with that produced by the helium of the earth's atmosphere. During the First World War the use of helium as a substitute for hydrogen in the inflation of dirigible balloons was proposed because of its greater safety. Helium, being inactive chemically, will not burn, whereas hydrogen is easily ignited and burns with explosive violence. Helium is also next in weight after hydrogen (atomic weight = 4), and hence is second to hydrogen in lifting power. When its use in balloons was first proposed, there was no available supply, but its existence in the natural gases of the Texas and Kansas oil fields became known, and its preparation from these sources was quickly carried forward by American chemists. It is now a practical commercial product in the United States and is used principally for the inflation of dirigible balloons. The other rare gases, xenon, neon, and krypton, are theoretically important but have no applied significance at the present time, except that neon is used for filling neon electric light bulbs and the tubes in certain electrically illuminated signs.

Relative Humidity.—The humidity of the air refers to the amount of water vapor present. *Relative humidity means the amount of water vapor in the air as compared with the maximum amount of moisture the air will contain.* If the air is saturated, i.e., contains as much water vapor as it is capable of holding at a given temperature, the relative humidity is 100 per cent; if half saturated, the relative humidity is 50 per cent; if two-thirds saturated, the relative humidity is 66 per cent. The relative humidity that is most comfortable for the human body varies inversely with the temperature of the surrounding atmosphere. Evaporation of water from the surface of the body removes heat. Water vapor in the atmosphere opposes evaporation from the body's surface. Therefore, in cold weather it is more comfortable when there is a fair amount of water vapor in the atmosphere which opposes loss of heat by evaporation of water from the body's surface. On the other hand, there is

greater comfort in hot weather when the humidity is relatively lower because the lower water vapor content of the atmosphere offers less opposition to loss of heat from the body by evaporation of water. In other words, one becomes chilled more readily in the winter time if the air is dry or has a low relative humidity; and one suffers greater discomfort from heat in the summertime if the atmosphere is excessively moist or has a high relative humidity. When the temperature ranges from 68° to 70° F. the most comfortable relative humidity varies from 60 to 45 per cent.

Ventilation.—The earlier ideas of ventilation regarded the admission of fresh air as necessary to supply more oxygen and to remove the carbon dioxide produced by respiration. In this respect it is evident that a continuous supply of oxygen is necessary for life, also that carbon dioxide is undesirable, if present in large amounts, since it increases the rate of respiration. It has been shown, however, that the atmosphere must reach an oxygen concentration as low as 13 per cent before harmful effects are produced in some individuals, whereas the air in the most crowded rooms seldom contains less than 20 per cent of oxygen. It is also true that the carbon dioxide content of the atmosphere, which is normally 0.03 per cent, seldom reaches twice the normal concentration in crowded rooms, and yet air containing ten times the usual amount of carbon dioxide may be breathed without ill effects. Laborers in breweries have been known to work continuously in atmospheres containing 1.5 to 2.5 per cent of carbon dioxide without serious consequences. It is, therefore, evident that the symptoms of discomfort resulting from poor ventilation are generally not due to a deficiency of oxygen, or excessive carbon dioxide in the air.

A great many carefully conducted experiments have shown that *the discomforts of exposure to vitiated air are the result of unfavorable humidity and temperature.* The atmosphere of a closed room in which people are living becomes warm and acquires a high relative humidity, because both heat and moisture are liberated from the surfaces of the

bodies of the people present and in the air expired from their lungs. The result of this increased humidity and temperature is an interference with evaporation from the skin, which retards the liberation of body heat and the elimination of waste products of metabolism through the skin. The latter conditions apparently produce the symptoms of poor ventilation, such as oppression, headache, nausea, dizziness, etc. Interference with the dissipation of body heat and the elimination of waste products by high relative humidity and increased temperature is, therefore, the chief reason for the discomforts of a poorly ventilated room.

The most important requirement of successful ventilation is the maintenance of correct humidity and temperature. The old custom of admitting fresh air to a room is effective because it keeps down the relative humidity by removing moisture, and produces a more desirable temperature. Ventilation engineers estimate that for each person in a room there should be admitted from 2,000 to 3,000 cubic feet of fresh air per hour. Air-conditioning of large buildings is accomplished by devices for controlling humidity and temperature and for removing dust particles which serve as mechanical carriers of bacteria. In many large theaters and public buildings, the practice at the present time is to change the air rapidly by means of blower and exhaust fans. The best system is to force the air through sprays of water, which filters it free from dust and bacteria and introduces enough water vapor to produce a desirable humidity. Our only practical method of ventilation in the home and most dwelling places, however, is to produce an exchange of air by opening the windows.

Questions for Study

1. What is the weight of the atmosphere at sea level? What is meant by a pressure of 1 atmosphere?
2. Name the principal constituents of the air.
3. Give the uses of five constituents of the air.

4. Name the members of the helium family. Discuss their activity. Why is helium used for inflating balloons?

5. What is relative humidity? What is the most comfortable relative humidity to the human body? Explain how high humidity causes discomfort to the body.

6. To what are the discomforts of exposure to vitiated air due?

7. What are the important requirements of successful ventilation? How much fresh air per hour is desirable for an individual? How is ventilation best secured in homes and dwelling places?

UNIT VII

A CHEMICAL FAMILY

CHAPTER XVI

THE HALOGEN FAMILY

Occurrence.—The closely related chemical family, which is found in Group VII of the periodic table, consists of four elements, fluorine, chlorine, bromine, and iodine. They are called the halogens, from a Greek word meaning "salt-former," because they combine with many metals to form a great abundance of salts. The halogens are found in Nature as compounds, being too active chemically to exist as free elements. Fluorine occurs in the mineral fluorspar, or calcium fluoride. Chlorine is found chiefly in sodium chloride in sea water, and in certain local deposits, such as the beds of ancient dried-up salt lakes. Bromine occurs along with chlorine in salt bed deposits in the form of sodium and magnesium bromides. Iodine is found principally as sodium iodide in sea water and sea weeds, and as sodium iodate ($NaIO_3$) in Chile saltpeter. In the human body fluorine is found in the bones and teeth in small amounts; chlorine, in the form of sodium chloride makes up a large part of the inorganic salts of the tissues, and is a constituent of the hydrochloric acid of gastric juice; and iodine is a constituent of thyroxin, the active principle of the thyroid gland. Bromine compounds do not occur naturally in the human body in significant amounts.

Properties and Periodic Relationships.—The properties and certain chemical relationships of the elements in the halogen family are shown in Table VII on page 177. This table shows a gradual change in physical and chemical properties, which is in the same order as the elements vary in atomic numbers. As the atomic numbers of these elements increase, their melting points and boiling points rise; their physical state changes in the order of gas, liquid, solid;

their color changes from pale yellow to a dark red; and their chemical activity decreases with increase in atomic numbers. This gradation of properties according to change in atomic numbers is one of the fundamental relationships between the elements, which we have previously discussed in the chapter upon the Periodic Law. It definitely indicates that the properties of the elements are dependent upon their atomic numbers.

TABLE VII

TABLE SHOWING GRADATION OF PROPERTIES OF THE HALOGEN FAMILY

ELEMENT	ATOMIC NUMBER	MELTING POINT IN DEGREES C. (RISES)	BOILING POINT IN DEGREES C. (RISES)	PHYSICAL STATE	COLOR	CHEMICAL ACTIVITY
FLUORINE	9	−223	−187	Gas	Pale Yellow	Most active
CHLORINE	17	−102	− 33.6	Gas	Greenish Yellow	Second in order of activity
BROMINE	35	−7	+59	Liquid	Brownish Red	Third in order of activity
IODINE	53	+107	+175	Solid	Dark Red	Fourth in order of activity

Uses.—Fluorine and hydrofluoric acid (HF) will attack glass. Hydrofluoric acid is, therefore, used for etching glass.

Chlorine is a powerful disinfectant. It is applied with excellent results in the purification of city water supplies, being introduced in the form of liquid chlorine or chlorinated lime (bleaching powder). Solutions containing chlorine in water are used extensively for irrigating and disinfecting wounds. One of these preparations is Dakin's solution, which is a mixture of sodium hypochlorite, sodium chloride, and boric acid. Chlorine, applied in the form of bleaching powders ($CaOCl_2$), is an efficient bleaching agent but is subject to the limitation that chlorine will injure

many materials to which it is applied. Chloroform, chloral, and carbon tetrachloride are chlorine compounds that are used in medicine. In the human body the compounds of chlorine are indispensable. Sodium chloride is essential for the vital activities of the tissues, and hydrochloric acid is necessary for gastric digestion.

One of the salts of bromine, sodium bromide, is used as a nerve sedative. Bromine also has disinfecting properties, but is not used for this purpose since chlorine is cheaper and more efficient.

Iodine is a valuable disinfectant. It is used chiefly in the form of tincture of iodine, which is a 7 per cent solution of iodine in alcohol, to which potassium iodide (5 per cent) is added. Potassium iodide is introduced into tincture of iodine because it makes iodine more soluble in water and will prevent iodine from precipitating if the tincture is diluted with water. Iodine in the form of some of its salts, like potassium iodide, is essential in the diet to prevent the development of simple goiter. The introduction of potassium iodide into the diet in regions where iodides are deficient in the drinking water has given excellent results in the prevention of this condition. Potassium iodide is also used to bring about the solution of the gummatous lesions of syphilis, and the absorption of abnormal tissues in other diseases.

Questions for Study

1. What is a chemical family?
2. Name the members of the halogen family. Why are they called the halogens?
3. Referring to the table of halogens, give two important properties of fluorine. Of chlorine. Of bromine. Of iodine.
4. Consulting the table, show the relationships of the members of the halogen family.
5. What is the relationship of the properties of these elements to their atomic numbers?
6. What are the uses of fluorine? Chlorine? Bromine? Iodine?

UNIT VIII
METALS AND NON-METALS

CHAPTER XVII
SOME IMPORTANT METALS

Metals and Non-Metals.—Metals are defined as those *elements whose oxides react with water to form bases.* For example, sodium, potassium, and calcium are metals. When the oxides of these elements react with water, sodium hydroxide, potassium hydroxide, and calcium hydroxide, substances which are typical bases, are formed.

A non-metal is an element whose oxide reacts with water to form an acid. Sulfur, phosphorus, and nitrogen are examples of non-metals. When the oxides of sulfur, phosphorus, and nitrogen are treated with water, they form sulfuric acid, phosphoric acid, and nitric acid, respectively.

The following distinctions between metals and non-metals will give a satisfactory conception of these two classes of substances:

METALS	NON-METALS
1. BASE-FORMERS. The oxides of metals react with water to form bases.	1. ACID-FORMERS. The oxides of non-metals react with water to form acids.
2. METALLIC LUSTER. The metals as a class will reflect light when polished.	2. As a rule, non-metals do not reflect light.
3. DUCTILITY OR TENACITY. Many metals can be drawn out into thin wires, which offer considerable resistance to pulling or twisting.	3. Non-metals are not ductile.
4. MALLEABILITY. Most metals are capable of being hammered into thin sheets, a property known as malleability.	4. As a class, the non-metals are not malleable.
5. ELECTRICAL CONDUCTIVITY. The metals as a class are good conductors of the electric current.	5. Non-metals are poor conductors of electricity.
6. SOLIDS. All metals, except mercury, are solids at ordinary temperatures.	6. Non-metals are solids, or liquids, or gases.
7. FORM POSITIVE IONS. The metals form positive ions when their compounds are dissolved in water.	7. FORM NEGATIVE IONS. Non-metals form negative ions when their compounds are dissolved in water.

Sodium and Potassium.—These two elements belong to a closely related chemical family called the "alkali metals" (in Group I of the Periodic Table), of which lithium, cesium and rubidium are the other members. Sodium and potassium are somewhat similar in properties, potassium being the more active chemically. They are soft, silvery white solids. They combine readily with most non-metals. They react violently with water, liberating hydrogen and forming sodium or potassium hydroxides, which are very strong bases. Sodium and potassium react so readily with water and oxygen that they have to be kept under kerosene. Sodium salts give a yellow color to the Bunsen flame. Potassium compounds impart a violet color to a flame. The salts of sodium and potassium occur rather abundantly in nature, and are important constituents of the human body. Both sodium and potassium compounds are constituents of plant tissues, but potassium compounds are the more essential in relation to plant life. Consequently, potassium salts are important fertilizers, since soils are often deficient in, or are easily exhausted of, their potassium constituents.

Calcium.—Calcium belongs to a chemical family called the "alkaline earth metals" which falls in Group II of the Periodic Table. The members of this family, in addition to calcium, are beryllium, magnesium, barium, strontium, and radium. Calcium is a silvery white metal, which is soft and easily cut or rolled, and tarnishes in air due to its combination with oxygen to form the oxide. It reacts with water, liberating hydrogen and forming calcium hydroxide. It also combines with many non-metals when heat is applied. It exists in nature in the form of some very important compounds, chief of which are calcium carbonate, calcium phosphate, and gypsum, or calcium sulfate. Calcium salts are important constituents of the tissues of the body, especially the bones and teeth.

Magnesium.—Magnesium is a white metal. It has a tenacity that permits it to be rolled into a ribbon. It will react

with water, liberating hydrogen, when the water is boiling hot. It combines with most non-metals when heat is applied. It oxidizes but very slightly at ordinary temperatures and may, therefore, be kept exposed to dry air. When burned, it produces a very brilliant white light, hence magnesium is used in the preparation of "flashlight" powders for night photography, and in the production of star shells for military purposes. Magnesium salts are constituents of the tissues of plants and animals.

Iron.—Pure iron is a silvery lustrous metal that is soft, malleable, and ductile. It is not found in nature as the free element, its chief occurrence being in the form of iron oxides and iron carbonate. It is a constituent of hemoglobin, the oxygen-carrying compound of the blood. The great industrial importance of iron is its extensive use in manufacturing structural materials. We will discuss briefly the three following structural substances of which iron is the chief constituent.

1. *Cast iron* is iron mixed with 2 to 5 per cent of carbon and small amounts of silicon, sulfur, manganese, and phosphorus. It is hard and brittle, with little tensile strength. It is used in manufacturing such materials as stoves and radiators, which do not have to undergo much strain.

2. *Wrought iron* is produced by refining cast iron until it is about 99.8 per cent pure. It is not as hard as cast iron, but it is ductile and malleable, and has great tensile strength. This form of iron is used for manufacturing chains, bolts, and iron wire.

3. *Steel* is iron mixed with 0.2 to 2 per cent of carbon usually, but there are other varieties of steel formed by mixing iron with other elements, such as silicon, manganese, chromium, and nickel. Steel is hard and yet possesses tensile strength. It is used to manufacture rails, bridge girders, cutting tools of all kinds, grinding machinery, armor plate, and all such materials that require great strength and resistance to wear.

Mercury.—Mercury was known to the early alchemists, who ascribed to it many mysterious properties. It is a silvery white liquid. It is the only metal that exists in the liquid state at ordinary temperatures. It has a high density, being 13.6 times heavier than water. Under appropriate conditions, it combines with non-metals, forming many compounds. Mercury vapors and the soluble compounds of mercury are severe poisons. Mercury is used in the construction of thermometers, barometers, and various gas measuring devices. It is also used in medicine in the form of a salve—unguentum hydrargyri.

Mercuric and Mercurous Chlorides.—These two salts of mercury are used extensively in medicine. They have widely differing properties and will cause disaster if confused with each other.

Mercuric chloride ($HgCl_2$), called also bichloride of mercury, is highly poisonous, and is a valuable disinfectant. Mercurous chloride (HgCl), or calomel, is not poisonous, and is used as a purgative. Calomel is not poisonous because it is not soluble in water. If it were soluble, the mercury atom of this compound would produce as toxic an effect as the mercury atom of bichloride of mercury.

Bismuth.—Bismuth is a grayish white metal. It is used principally in the preparation of alloys with low melting points, such as Wood's metal, which melts at 60° C. Its chief importance in medicine is as a constituent of bismuth subnitrate and bismuth subcarbonate. These salts are used in treating conditions characterized by irritation along the alimentary tract. They are insoluble and form a coating over an irritated or ulcerated surface which protects against mechanical injury from food and chemical injury from digestive juices. Bismuth subnitrate is also used in taking x-ray pictures of the alimentary tract. The x-rays will not penetrate this substance to the same degree as they do the tissues not coated with it, hence after the ingestion of bismuth salts a shadowed outline of the stomach and intestines may be observed with the fluoroscope, or may

be reproduced upon x-ray plates. The presence of an ulcer can usually be revealed by an x-ray shadowgraph taken with the aid of bismuth subnitrate. An ulcerated area becomes coated more deeply with this substance than the surrounding tissues and will obscure the passage of the rays to a greater extent. Consequently, the region of an ulcer will appear as a darker area upon the shadowgraph.

Radium.—Radium was discovered by Pierre and Marie Curie in 1898. It was first isolated in the form of its salt, radium chloride. Later the pure element was prepared by Madame Curie. Pure radium is a white, lustrous metal. It is difficult to prepare and to keep in the pure form and is, therefore, used in the form of radium chloride or radium bromide.

Radium owes its name to the fact that it constantly radiates or emits energy. One gram of radium gives off more than enough heat to raise its own weight of water from the freezing point to the boiling point every hour; or, in more exact terms, the energy liberated by one gram of radium is equivalent to 120 calories per hour. It has been estimated that the amount of heat that is liberated by one gram of radium during its period of activity is equivalent to the heat that would be obtained from burning about one ton of coal. This remarkable radiation of energy is the result of changes which really are a disintegration of the radium atom. These changes are discussed below.

Radium is used in medicine for the treatment of cancer. The radiations from radium will destroy both normal and abnormal tissues. These radiations are applied directly to a malignant growth, care being taken to screen the healthy tissues by means of materials through which the rays from radium do not pass readily. Such treatment has been found valuable in cases of abnormal growths to which radium emanations can be applied satisfactorily. Radium is kept in lead containers to prevent exposure to its rays, since lead is a substance through which radium emanations pass very poorly, or not at all if a thick layer is used.

Radium is a very expensive substance, being worth about $20,000 per gram. This high price is due to the scarcity of the substance.

Radioactivity.—The phenomenon of radioactivity was first observed as a property of uranium. In experiments with this element, Becquerel in 1896 noticed that it gives off emanations which affect a photographic plate and discharge a charged electroscope. Later the Curies isolated polonium and radium, and found that these elements are a million times more radioactive than uranium.

Investigations of the properties of radioactive elements have shown that there are three kinds of emanations given off by these substances, namely, alpha, beta, and gamma rays.

Alpha rays are atoms of helium which have been stripped of two electrons and, therefore, bear two positive charges. These particles are shot off from radioactive material at a speed of 18,000 miles per second. They do not have the penetrative power of beta or gamma rays, being stopped by a sheet of paper or a few centimeters of air.

Beta rays are negative electrons. They are ejected from radioactive substances at a velocity of 160,000 miles per second. Beta rays have about one hundred times the penetrative power of alpha rays; they will pass through several millimeters of aluminum or as much as ten feet of air before being stopped. Beta rays are the same fundamental particles as the cathode rays emitted from an x-ray tube.

Gamma rays are emanations of particles of energy. They have great penetrative power. They will pass through several inches of lead. In passing through gases they ionize the latter, a property possessed also by alpha and beta rays. There is some parallelism between gamma rays and the x-rays emitted by an x-ray apparatus.

The separation of the three kinds of rays emanating from radioactive substances is accomplished with a magnet. If radium is placed in an electromagnetic field, the alpha rays, being positive, will pass to the negative pole, and the beta rays, being negative, will pass to the positive pole. Gamma rays are not deflected by a magnetic field.

Radioactivity is a disintegration or transmutation of matter. Atoms of such substances as uranium, actinium, thorium, polonium, and radium undergo continuous disintegration, giving off some or all of the three types of particles described above, and are thus changed into atoms of other elements. To illustrate, let us consider the behavior of radium, as shown in Table VIII.

TABLE VIII

ELEMENT	TYPE OF RAY EMITTED	HALF-LIFE PERIOD
Radium	Alpha	1690 years
Radon	Alpha	3.9 days
Radium A	Alpha	3 minutes
Radium B	Beta, Gamma	27 minutes
Radium C	Alpha, Beta, Gamma	20 minutes
Radium D	Beta, Gamma	16.5 years
Radium E	Beta	5 days
Radium F (Polonium)	Alpha, Gamma	136 days
Lead	None	Does not disintegrate

In column one of Table VIII there are shown radium and its disintegration products. Each element in this column disintegrates, giving rise to the element beneath it. The type of rays emitted by each element is shown in column two. In column three is shown the half-life period of each element. By half-life period is meant the time that elapses while the element loses one-half of its mass by radioactive disintegration. The end-product resulting from the disintegration of radium is lead. Lead does not undergo transmutation.

Artificial Radioactivity.—Recently methods have been discovered for imparting radioactivity to elements which do not possess this property naturally. These methods consist essentially of procedures for bombarding an element with very small particles possessing great energy. The first success along this line was achieved by Irene Curie Joliot, daughter of Marie Curie, and her husband, Frederick Joliot. These workers directed the fast moving alpha particles emitted by polonium upon sheets of aluminum and found that the latter remained radioactive for several minutes after removing the bombarding source. Later, machines were developed for projecting bombarding particles with high speed and great energy upon targets of substances

to be made active. These machines are capable of imparting energies of two to ten million electron volts to particles in their fields of activity. The bombarding particles, or "bullets," used in such shooting are protons (hydrogen nuclei), deuterons (nuclei of heavy hydrogen), neutrons, and alpha particles. When these tiny projectiles, moving at a high velocity, strike upon the surface of a substance, a small number of them collide with the nuclei of the atoms of the bombarded material. The "head-on" collisions with atomic nuclei cause some disintegration in the latter. From such atomic collisions there are emitted sometimes positive or negative electrons and sometimes protons or neutrons. As a result of these collisions new elements are formed which may be radioactive for a time.

By bombardment techniques radioactivity has been imparted to many of the elements not having this property. In most instances the period of radioactivity is short, lasting only a few seconds or minutes, but a more lasting activity has been imparted to some of the elements. Thus radioactive sodium, produced by bombardment of metallic sodium or sodium salts, with fast moving deuterons, has a half-life period of fifteen hours; and radio-phosphorus and radio-sulfur have half-life periods of fifteen days. The success that has been obtained in producing artificial radioactivity suggests that this procedure may be used in the future to supplement our supply of naturally radioactive substances.

The bombardment of platinum with fast-moving deuterons results in the formation of gold. Thus the dream of the alchemists, the transformation of another element into gold, has been achieved. But the amount of gold obtained in this way is small, the procedure is very costly, and the source material, platinum, is more valuable than gold; hence this process will never be put to commercial use.

Questions for Study

1. Define a metal. A non-metal.

2. Give several distinctions in the properties of metals and non-metals.

3. State the properties of sodium and potassium.

4. State the properties of calcium. Name several important calcium compounds in nature.

5. Relate the properties of magnesium. What is the principal use of magnesium?

6. Give the properties of pure iron.

7. What is cast iron? Wrought iron? Steel? What are the uses of each?

8. Describe mercury.

9. What is the difference between mercuric and mercurous chlorides? Explain why mercurous chloride is not poisonous.

10. What is the importance of bismuth in medicine?

11. Explain how bismuth subnitrate enables x-ray pictures to be taken.

12. What are the properties of radium?

13. To what property does radium owe its name? Describe this unusual property.

14. What are the medical uses of radium? Why is radium so expensive?

15. What is radioactivity?

16. Describe the three types of emanations ejected from radioactive substances.

17. Tell how radioactivity is imparted to substances which do not have this property naturally.

18. How is transmutation of the elements accomplished?

CHAPTER XVIII

SOME IMPORTANT NON-METALS

Sulfur.—Sulfur is a very common element. It is found as the free element in large deposits in Louisiana and Texas, and also in certain volcanic regions in Mexico, Sicily, and Japan. The chief sulfur compounds of Nature are the sulfides of iron (FeS), lead (PbS), zinc (ZnS), and copper (CuS), and the sulfates of calcium ($CaSO_4.2\ H_2O$), barium ($BaSO_4$), strontium ($SrSO_4$), and magnesium ($MgSO_4.7\ H_2O$). Sulfur is also a constituent of most proteins and is, therefore, found in the tissues of animals and plants.

Properties.—Sulfur is a pale yellow solid, insoluble in water but soluble in carbon disulfide. It is tasteless and odorless. It exists in several allotropic forms. In this respect, it will be recalled, it resembles oxygen and ozone. Sulfur is inactive at ordinary temperatures, but reacts with many substances when heat is applied. It burns with a blue flame, forming sulfur dioxide.

Uses.—Sulfur is used in the manufacture of vulcanized rubber, certain kinds of matches, black gunpowder, and depilatories. Mixed with lime, it is applied as a spray to fruit trees and plants to kill fungi which are harmful to their host.

Important Sulfur Compounds.—

Sulfur dioxide is a colorless gas formed when sulfur is burned in air or oxygen.

$$S + O_2 \rightarrow \underset{\text{Sulfur dioxide}}{SO_2}$$

When inhaled, it produces a disagreeable, suffocating effect. It is used for bleaching straw, wool, and silks, and for fumigating rooms infected with vermin. When dissolved in water, it forms sulfurous acid.

Sulfur trioxide is a white solid formed by the oxidation of sulfur dioxide.

$$2\ SO_2 + O_2 \rightarrow \underset{\text{Sulfur trioxide}}{2\ SO_3}$$

This oxide is important in that it forms sulfuric acid when dissolved in water.

Sulfuric acid is prepared by oxidizing sulfur dioxide to sulfur trioxide with the aid of a catalyst and then dissolving the trioxide in water.

$$2\ SO_2 + O_2 \rightarrow \underset{\text{Sulfur trioxide}}{2\ SO_3}$$

$$SO_3 + H_2O \rightarrow \underset{\text{Sulfuric acid}}{H_2SO_4}$$

Sulfuric acid is a heavy, oily, white liquid. It is highly soluble in water. When the concentrated acid is mixed with water, there is a marked evolution of heat. It ranks as a strong acid, but is not as strong as hydrochloric or nitric acids. It has all the characteristic properties of an acid, and, when hot, behaves as an oxidizing agent. It has a strong affinity for water and is a good drying agent. Its affinity for water is so marked that it will abstract water from compounds containing hydrogen and oxygen. For instance, if concentrated sulfuric acid is spilled upon wood, or is mixed with sugar, water is withdrawn from these materials, and a charred mass of carbon remains. The reaction is as follows:

$$\underset{\text{Sugar}}{C_{12}H_{22}O_{11}} + H_2SO_4 \rightarrow 12\ C + 11\ H_2O + H_2SO_4$$

Sulfuric acid is used in the manufacture of explosives, dyes, and many chemicals, and in the purification of petroleum. It is perhaps more indispensable to industry than any other chemical reagent.

Magnesium Sulfate (Epsom Salts). This compound has the formula $MgSO_4.7\ H_2O$. It is a white crystalline substance whose principal use in medicine is as a laxative.

Sodium Sulfate (Glauber's Salts), $Na_2SO_4.10\ H_2O$, is used in medicine as a laxative.

Barium Sulfate, $BaSO_4$, is given internally previous to taking x-ray pictures of the alimentary tract. It interferes

with the passage of x-rays and permits the taking of shadowgraphs in the same manner as bismuth subnitrate, which we have previously described (page 182).

Hydrogen Sulfide.—Hydrogen sulfide (H_2S) is found in the waters of sulfur springs and in the gases of volcanoes. It is also emitted from decaying organic matter containing combined sulfur, such as bad eggs or meats. Hydrogen sulfide is a colorless gas with a very disagreeable odor. It is a poisonous substance, being fatal if inhaled for a considerable time. It is moderately soluble in water and, when in solution, forms a weak acid. It is a very important reducing agent. The sulfur of hydrogen sulfide will combine with many metals, producing insoluble sulfides of different colors. It is this substance which blackens silverware by the formation of black silver sulfide.

Phosphorus.—Phosphorus belongs to a chemical family of which nitrogen, arsenic, antimony, and bismuth are members. This family, like the halogen family, shows the usual similarities and gradations of properties of a chemically related group.

Phosphorus owes its name to the fact that it glows in the dark, the word *phosphorus* meaning "bearer of light." It is too active an element to occur free, and is found chiefly in the form of phosphates, which are salts of phosphoric acid, the principal acid of phosphorus. Phosphates are found in the soil in varying amounts, and in large quantities in certain phosphate rock deposits, such as in South Carolina and Florida. Phosphorus is a constituent of many important compounds in the human body. About 85 per cent of the solid matter of bones and teeth is composed of calcium and magnesium phosphates. The blood, brain, and nerve and muscle tissues contain phosphorus compounds, and the urine and feces contain phosphates as constant excretory products. Phosphorus compounds are constituents of plant tissues also. A soil, to be fertile, must contain adequate soluble phosphates, which are essential for the promotion of plant growth.

Phosphorus was discovered accidentally in 1669 by the German alchemist Brandt, who prepared this element by heating dried urine and charcoal in a clay retort. It is prepared at the present time by essentially the same procedure, which consists of heating phosphate rock, or bone ash, with sand and charcoal.

Phosphorus is a solid which exists in at least two elementary forms, white phosphorus and red phosphorus. These two forms of the same element have widely differing properties. White phosphorus is very inflammable, igniting at 35° C.; it is soluble in carbon disulfide, ether, and olive oil; and it is poisonous. Red phosphorus will not burn until a temperature of 240° C. is reached; it is not soluble in the solvents of white phosphorus; and it is not poisonous. Red phosphorus is prepared by heating the white form to 250° C. in the absence of oxygen. White phosphorus is so inflammable that it must be kept under water. The temperature of the body will ignite it, hence it cannot be held in the hands. Both red and white phosphorus oxidize to phosphorus pentoxide, which forms phosphoric acid when dissolved in water.

$$4\,P + 5\,O_2 \rightarrow 2\,P_2O_5$$
Phosphorus pentoxide

$$P_2O_5 + 3\,H_2O \rightarrow 2\,H_3PO_4$$
Phosphoric acid

Uses.—The chief use of the element phosphorus is in the preparation of matches. For this purpose white phosphorus was once used, but, as it is so poisonous to workers who are exposed to its vapors, its use has been discontinued either by statute or prohibitive taxation. Matches are now made from red phosphorus, or a compound of sulfur and phosphorus—tetraphosphorus trisulfide, P_4S_3. The sodium salts of phosphoric acid are used in medicine. Disodium phosphate (Na_2HPO_4) is used as a mild laxative.

Arsenic.—Arsenic is a gray solid which resembles metals in appearance, but is an acid-former and, therefore, a non-

metal. Arsenic and its compounds are very poisonous. For this reason they are valuable as insecticides, weed killers, and destroyers of disease-producing microorganisms. Paris green, or copper arsenite, and lead arsenate are applied by agriculturists as sprays to certain vegetable crops and fruit trees to kill destructive insects. Calcium arsenate has been found especially valuable in combating the boll weevil which infests the cotton plant. In medicine, several organic compounds of arsenic, such as arsphenamine, neoarsphenamine, have been found valuable in treating certain diseases, like syphilis and yaws, which are caused by protozoa.

Boron.—This element is of importance chiefly as a constituent of boric acid, H_3BO_3, and borax, $Na_2B_4O_7$. Boric acid is an extremely weak acid. It is a mild antiseptic and its saturated solution makes a very satisfactory eye wash. Borax, being a salt of a weak acid and a strong base, forms an alkaline solution when dissolved in water. Its mild alkalinity makes it applicable to laundry work. Boric acid is slightly poisonous. Care should, therefore, be taken not to apply this substance excessively to the body, as cases of serious poisoning from absorption of boric acid used in antiseptic dressings have been reported.

Questions for Study

1. Describe the occurrence of sulfur.
2. What are the properties of sulfur? Give its uses.
3. What are the principal uses of sulfur dioxide?
4. How is sulfuric acid prepared?
5. Give the properties of sulfuric acid.
6. What is the formula for Epsom salts? Glauber's salts?
7. What is the use of barium sulfate in medicine?
8. What are the properties of hydrogen sulfide?
9. Discuss the occurrence of phosphorus in the human body.
10. Give a discussion of the contrast in the properties of white phosphorus and red phosphorus.
11. What are the uses of phosphorus?
12. What are the uses of arsenic?
13. What are the uses of boric acid? What care should be taken in its use?

UNIT IX

THE INORGANIC CHEMISTRY OF CARBON

CHAPTER XIX

CARBON AND SOME INORGANIC CARBON COMPOUNDS

Occurrence and Importance.—Carbon is an exceedingly important element. It exists as the free element in Nature in the form of coal, graphite, and diamonds. It is also the characteristic element of the great class of compounds known as organic compounds. About 500,000 organic compounds are known at the present time, and this number is increasing rapidly due to the advances of synthetic chemistry. The carbon compounds are so numerous and so important that a separate branch of chemistry, known as organic chemistry, is devoted to a special consideration of them.

As the central element in organic compounds, carbon is closely related to life. The tissues of living things are composed essentially of carbon compounds; and the energy exchanges which maintain life result from the oxidation of carbon compounds. Carbon is also wonderfully important as the principal element in compounds that act as storehouses of energy from the sun, since the energy of sunlight is used by plants in the formation of certain carbon compounds and this energy is later released when these compounds are utilized as foods, or are burned as fuels.

Properties.—Carbon is an allotropic element; that is, it exists in several elementary forms. All elementary forms of carbon are tasteless, odorless, crystalline solids. The crystalline nature of diamond and graphite is apparent to the eye; but the crystals of the other forms of carbon, such as coal, coke, lampblack, and charcoal, are too minute to be seen even with a microscope, and their existence has been revealed only by x-ray methods of examination. The dif-

ferent forms of carbon are highly insoluble, and are infusible and non-volatile; that is, they can be neither melted nor vaporized by the temperatures we are capable of producing at the present time. Chemically carbon is inactive at ordinary temperatures, but it will combine with oxygen, or burn at elevated temperatures. A great deal of energy is liberated when carbon burns.

Diamond.—Pure diamond is a colorless, transparent, crystalline substance that is very hard and has a high refractive index. It is inactive chemically, but it will burn when heated in oxygen to a temperature of about 800° C.

Natural diamonds are found chiefly in South Africa, India, and Brazil. The naturally occurring diamonds are of different grades of purity. Some are practically pure and are used for jewelry, since pure diamond has the ability to refract light, and hence "sparkles" in the light. Other grades of diamonds have small amounts of impurities in them, which will give them poor optical qualities, and for this reason are of no value as jewelry. The impure forms of diamond are very valuable, however, because of their hardness, and are used for grinding the perfect diamonds into shape, for cutting glass, and for pointing rock drills.

Graphite.—Graphite is found as natural deposits in Ceylon, Siberia, and Austria. It differs widely from the diamond in its physical properties, even though it is the same element. It is lighter in weight than the diamond, is not hard, and is black in color. It is inactive chemically. It is used in the manufacture of lead pencils, stove polish, shoe polish, black paints, and crucibles for heating to high temperatures.

The Charcoals.—*Principle of Preparation.* The charcoals are made by heating organic matter containing carbon in the absence of oxygen or air. If organic matter is heated in the presence of oxygen, the carbon is oxidized to carbon dioxide, which passes off into space; if, on the other hand, oxygen is excluded when carbon compounds are heated, the volatile matter is removed, but carbon, being non-volatile, remains as a residue. Heating organic matter to high tem-

peratures, with the exclusion of oxygen, is therefore, the principle involved in the preparation of charcoals.

Wood Charcoal.—When wood is heated to high temperatures in kilns which do not permit the access of oxygen, the hydrogen and oxygen of the wood are removed as water, and wood alcohol, acetone, acetic acid, and other volatile substances are driven off. The residue is wood charcoal, an elementary form of carbon. Wood charcoal is used in metallurgy for the extraction of metals from their ores; in the manufacture of black gunpowder; in the manufacture of steel; and as a filtering agent to remove undesirable substances from a solution.

Animal Charcoal.—This charcoal is made by heating animal tissues (blood, bones, horns, hides, hoofs) in the absence of oxygen. The residue obtained in this process is a charcoal, mixed with calcium phosphate and other inorganic salts that are peculiar to animal tissues. Animal charcoal is used in the refining of sugar, a process described under Adsorption.

Adsorption.—Charcoals have the property of collecting gases to which they are exposed and of removing particles of matter from liquids that are poured through them. This behavior is called *adsorption*. In adsorption the charcoal does not form a compound with the substances it collects but apparently condenses and binds them upon its surfaces. Charcoal is a highly porous substance, and has a relatively large amount of surface. It has been estimated that one ounce of a good grade of charcoal has a surface area of 20,000 square yards. In addition to this enormous surface area, charcoal has a high degree of surface attraction for certain substances. Charcoal is, therefore, an excellent adsorbing agent.

One of the greatest applications of adsorption by charcoal in industry is in the refining of sugar. In sugar refineries, raw "brown" sugar solution is passed through large tanks, 20 to 30 feet deep, of animal charcoal. In passing through charcoal, brown organic matter and other substances (but

not sugar) are removed by adsorption from the crude syrup, and by the time the latter reaches the bottom of the filtering bed it has been freed of all objectionable matter. The colorless solution obtained is drained into appropriate containers, where it is concentrated and the sugar is crystallized. In this manner crude brown sugar is converted into the pure refined sugar of commerce.

Another application of adsorption by charcoal is in the preparation of gas masks. Cocoanut charcoal is especially efficient in removing poison gases from the air.

The Formation of Coal.—Coal consists chiefly of carbon and compounds of carbon. It originated from plant material which, the evidence indicates, must have been produced upon the surface of the earth in past ages. In order to understand its formation we must apply the principles noted in the preparation of charcoal. Plant matter, when heated in the presence of oxygen, is oxidized, forming chiefly carbon dioxide and water; but when the supply of oxygen is removed, carbon does not burn but remains at the end of the heating process as a residue called charcoal. A similar process took place upon the earth's surface millions of years ago. Great forests of trees, ferns, and other plant material were inundated, first with water, later with solid matter, by the sudden changes in the crust of the earth, and in this manner layers of plant matter were stored beneath the earth's surface out of contact with air. The internal heat of the earth drove off the volatile products from this organic matter, and the pressure of deep columns of earth completed the process by squeezing the carbon residue into the various forms of coal.

The origin of coal, then, is from plants which once grew upon the earth's surface. These plants obtained the energy for their growth from the sun. Coal is, therefore, a product containing energy that originated from the sun millions of years ago. The energy of sunlight transmitted to the earth in the past thus appears as the energy of the present when coal is burned.

Some Carbon Compounds

Carbon Monoxide, CO.—Carbon monoxide is a colorless, odorless gas. It is formed when carbon is burned in an insufficient supply of oxygen.

$$2\,C + O_2 \rightarrow \underset{\text{Carbon monoxide}}{2\,CO}$$

In the above reaction there is not enough oxygen to oxidize the carbon to carbon dioxide, the compound that should be formed to satisfy the valence of carbon, hence carbon monoxide is formed. In the presence of sufficient oxygen, carbon and carbon monoxide will form carbon dioxide when they burn. Thus

$$C + O_2 \rightarrow \underset{\text{Carbon dioxide}}{CO_2}$$

$$\underset{\text{Carbon monoxide}}{2\,CO} + O_2 \rightarrow \underset{\text{Carbon dioxide}}{2\,CO_2}$$

Carbon monoxide burns with a blue flame. The blue flame that flickers over the top of a heap of burning coal is the flame of carbon monoxide. As the valence of carbon in carbon monoxide is not satisfied, this compound combines readily with many substances. It has great affinity for the hemoglobin of the blood, and is, therefore, a very dangerous poison. One volume of carbon monoxide in 800 volumes of air will result fatally if breathed for about thirty minutes. Carbon monoxide combines with hemoglobin to form carboxy-hemoglobin, a stable compound, the hemoglobin part of which is no longer able to combine with oxygen. Carbon monoxide poisoning is thus a reduction in the amount of effective hemoglobin that can be used for carrying oxygen; or a reduction of the oxygen carrying-power of the blood. The victim of such poisoning dies from asphyxiation, or inability to get sufficient oxygen, because his active hemoglobin has been reduced to an amount below that which is necessary for the proper oxygenation of his tissues.

Carbon Dioxide, CO_2

Occurrence.—Carbon dioxide occurs in the air to the extent of 3 or 4 parts per 10,000, and is found in many natural waters. The carbon dioxide of the air originates principally from the combustion of carbon. This arises from the fires of dwelling places, the furnaces of industry, the respiration of animals, and from the decay of dead animal and vegetable matter.

Preparation.—

1. The simplest method of preparing carbon dioxide is by burning carbon in an abundance of oxygen.

$$C + O_2 \rightarrow CO_2$$

2. Another very easy method, the one used in the laboratory, is to mix an acid with a carbonate:

$$Na_2CO_3 + 2\,HCl \rightarrow 2\,NaCl + H_2O + CO_2$$

Properties and Uses.—Carbon dioxide is a colorless, odorless gas, slightly soluble in water. When dissolved in water, it forms a weak acid, known as carbonic acid, which gives to water a pleasant taste; hence the use of carbonated waters at soda fountains. It will not burn and hence is a valuable fire extinguisher. The explanation of the nonburning of carbon dioxide is that the carbon atom in the molecule is already "burned" or oxidized completely; that is, its valence is completely satisfied with the two atoms of oxygen it holds, and it, therefore, cannot combine with more oxygen. Carbon dioxide is heavier than air, and hence it will settle down upon a fire and "smother" the fire by preventing access of air. Carbon dioxide is not poisonous, and is, in fact, the normal stimulus of the respiratory center of the brain. If the amount in the blood and tissues is increased, however, either by breathing air containing excess carbon dioxide, or by faulty elimination of this substance from the body, respiration is stimulated unduly, and the individual pants, or breathes too rapidly. Plants use carbon dioxide in the synthesis of foods. We will consider this process later in the chapter upon carbohydrates.

Principle of the CO_2 Fire Extinguisher.—The carbon dioxide fire extinguisher contains a solution of sodium bicarbonate and a small bottle of sulfuric acid placed above the solution, near the top of the tank. The sulfuric acid bottle is stoppered with a heavy lead stopper, which remains in place when the apparatus is in an upright position but falls out when the tank is inverted. In case of fire, the apparatus is inverted, the stopper falls from the sulfuric acid bottle, and the acid and bicarbonate become mixed and react to form carbon dioxide. The latter accumulates in the tank, creating pressure, and finally water saturated with carbon dioxide is forced from the tank and sprayed upon the fire through a small nozzle attached to the tank. Fig. 30 illustrates the construction of a carbon dioxide fire extinguisher.

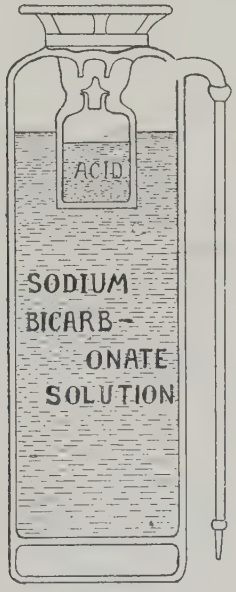


Fig. 30.—Diagram of a carbon dioxide fire extinguisher.

Carbonic Acid, H_2CO_3.—When carbon dioxide is passed into water, carbonic acid is formed.

$$CO_2 + H_2O \rightleftarrows H_2CO_3$$

This is a very weak acid. It is popularly known as "carbonated water."

Sodium Carbonate, Na_2CO_3.—Sodium carbonate is a salt which produces an alkaline solution when dissolved in water. Its alkalinity in solution is explained by the fact that it is a salt of a very weak acid, carbonic acid, and a strong base, sodium hydroxide. When dissolved in water, it undergoes hydrolysis, yielding a base that is stronger than the acid formed.

$$Na_2CO_3 + 2\ H_2O \rightleftarrows 2\ NaOH + H_2CO_3$$

In the above reaction sodium hydroxide, being a strong base, has a greater influence upon the solution than carbonic acid, consequently the solution is alkaline. Sodium carbonate is called "washing soda" from its use as a cleansing agent.

Sodium Bicarbonate, $NaHCO_3$.—Sodium bicarbonate is another salt of carbonic acid which produces a mildly alkaline solution when dissolved in water. It is a constituent of baking powders, and has medicinal applications as a neutralizing agent for hyperacidity and as an antidote for acid burns.

Calcium Carbonate, $CaCO_3$.—One of the common forms of calcium carbonate is limestone, the substance of which much rocky material upon the earth's surface is composed. Other familiar forms of calcium carbonate, which are more or less impure, are chalk, marble, sea shells, coral, pearls, and egg shells. Pure calcium carbonate is a white solid that crystallizes in two forms of crystals. Crystalline calcium carbonate is a very hard substance, hence it is valuable for building and construction purposes. It is insoluble in water, but decomposes rapidly in acids. When heated to high temperatures, it forms lime, or calcium oxide, and gives off carbon dioxide.

$$\underset{\text{Calcium carbonate}}{CaCO_3} + \text{heat} \rightarrow \underset{\text{Calcium oxide}}{CaO} + \underset{\text{Carbon dioxide}}{CO_2}$$

Baking Powders.—In making bread it is desirable to lighten, or "leaven," the heavy dough, which is composed of flour, fat, and water. This is accomplished by mixing in

the bread some substances which will liberate carbon dioxide. Carbon dioxide, being a gas, expands when liberated in the dough, and in this manner causes a spreading of the particles of the latter, a process commonly referred to as the "rising" of bread.

There are several ways to produce carbon dioxide in a raw bread mixture. The economical housewife makes biscuits by using sour milk and sodium bicarbonate as the "rising" agents; in this case the acid of the milk reacts with the bicarbonate and liberates carbon dioxide. Yeast is also used as a leavening agent because it is capable of producing carbon dioxide by fermenting the sugar of the dough. A third method of leavening bread is by the use of baking powders. All baking powders contain sodium bicarbonate and starch. The variation in the different brands of baking powders is in the weakly acidic substances used to react with the sodium bicarbonate and liberate carbon dioxide. Some manufacturers use cream of tartar, $KHC_4H_4O_6$, an acid salt of tartaric acid; some use acid sodium phosphate, NaH_2PO_4; and others use alum, $K_2Al_2(SO_4)_4 \cdot 24\ H_2O$, which forms a dilute acid when dissolved in water. In each case a weakly acidic substance is provided to react with the sodium bicarbonate and liberate carbon dioxide. In the case of cream of tartar, the reaction is as follows:

$$\underset{\substack{\text{Potassium}\\\text{hydrogen}\\\text{tartrate}\\\text{(Cream of tartar)}}}{KHC_4H_4O_6} + \underset{\substack{\text{Sodium}\\\text{bicarbonate}}}{NaHCO_3} \rightarrow \underset{\substack{\text{Sodium}\\\text{potassium}\\\text{tartrate}\\\text{(Rochelle salts)}}}{NaKC_4H_4O_6} + H_2O + \underset{\substack{\text{Carbon}\\\text{dioxide}}}{CO_2\uparrow}$$

Starch is introduced into baking powders because it absorbs moisture and prevents a reaction between the ingredients while in the container in which they are kept.

Questions for Study

1. Discuss the occurrence of carbon. What is its relation to life?
2. Give several properties of carbon.
3. What are the properties of diamond? What are its uses?
4. What are the uses of graphite?
5. Explain the principle of charcoal preparation.

6. What is adsorption?
7. Discuss two uses of animal charcoal.
8. Describe the formation of coal.
9. Where did much of the energy that is in coal originate?
10. Describe carbon monoxide.
11. Explain why carbon monoxide is poisonous.
12. What is the origin of the carbon dioxide of the atmosphere? How is carbon dioxide prepared? Give the properties of carbon dioxide.
13. What are the uses of carbon dioxide?
14. Explain the principle of the carbon dioxide fire extinguisher.
15. What is carbonic acid?
16. Explain the alkalinity of sodium carbonate.
17. What are the uses of sodium bicarbonate?
18. What is the importance of calcium carbonate?
19. Give the chemistry of bread making.
20. What ingredients are found in all baking powders? In what way do the baking powders upon the market differ from each other? What is the function of starch in baking powders?

UNIT X

ORGANIC CHEMISTRY

CHAPTER XX

ORGANIC CHEMISTRY: GENERAL PRINCIPLES

Organic chemistry is the *chemistry of carbon compounds.* The term "organic" arose from the relationship of this branch of chemistry to organic, or living, matter. In the early history of chemistry it was believed that there were many substances which could not be made by the chemist working in his laboratory and could result only from the vital activity of living things. But about one hundred years ago (1828) the German chemist, Wöhler, prepared urea, a compound of animal origin, from ammonium cyanate, an inorganic substance, and this synthesis in the laboratory showed that the vital influence of the living organism is not necessary to produce "organic" compounds. Since Wöhler's epoch-making discovery, many other compounds have been prepared by chemists which, it was once believed, could be produced only by plants and animals. Sugars, fats, protein-like substances, uric acid, alcohol, and many other products of living matter have been made in the chemical laboratory. Thus the old idea that vital or living influences create a different class of compounds and a different kind of chemistry has been shown to be untrue. The early division of chemistry into inorganic and organic chemistry is still retained for its convenience, however, but organic chemistry is now defined as the chemistry of carbon compounds since carbon is the characteristic element in all organic compounds.

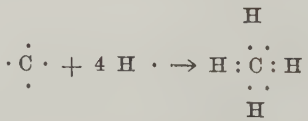
When first taking up the study of organic chemistry, the student may be amazed at the size of organic molecules and may be discouraged with the apparent difficulty of understanding organic reactions. But organic reactions are really

less difficult to understand than they at first seem. Although the molecule of organic substances may be quite large, the student will soon realize that organic reactions involve only a small part of the molecule, and it will soon be noted that the many reactions which take place in organic chemistry can be grouped under a few general types. It is important, then, in studying organic reactions, to fix one's attention upon that part of the molecule which is responsible for the reaction, and to realize that certain atoms, or groups of atoms, react the same way at all times and the rest of the molecule remains inactive. The reactive part of the molecule is the *characteristic group,* and it is upon the basis of characteristic groups, which have characteristic properties, that organic compounds are classified. In a course of this kind it is neither possible nor necessary to enter deeply into the chemical reactions of organic compounds. We will attempt to present only a general idea of organic chemistry by (1) giving a classification of organic compounds, emphasizing the characteristic group of each class; and (2) pointing out a few important physical and chemical properties of the compounds selected as examples.

Some Fundamental Principles of Organic Chemistry

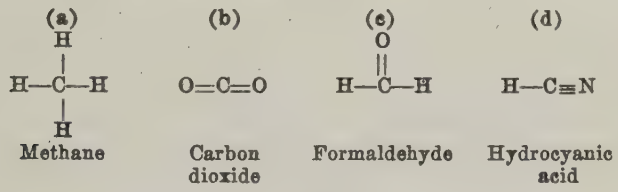
1. Carbon, the characteristic element of organic compounds, has a valence of 4. This is represented graphically as follows:

2. Carbon usually reacts chemically by a *sharing* of valence electrons. For example, if we designate the valence electrons of atoms by dots placed around the symbol for the element, we may represent the combination of carbon with hydrogen as follows:



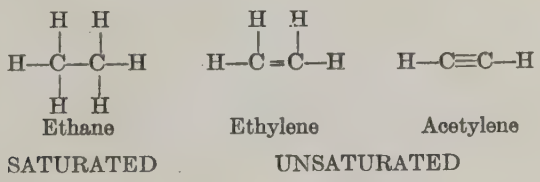
In the compound formed above carbon *shares* 4 pairs of electrons with hydrogen. In organic chemistry the valence bond of carbon is usually considered as the equivalent of 2 shared electrons.

3. Carbon may combine with (a) four univalent atoms; (b) two divalent atoms; (c) two univalent atoms and one divalent atom; (d) one univalent atom and one trivalent atom. The following examples illustrate each case:

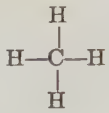


4. Carbon atoms have a great tendency to combine with themselves and form molecules containing a large number of atoms. On account of this property, organic compounds, as a class, contain far more atoms in their molecules than inorganic compounds. The proteins, for example, are organic compounds whose molecules contain hundreds of atoms; and carbohydrates, fats, dyes, and certain drugs are organic compounds whose molecules are very large when compared with inorganic substances.

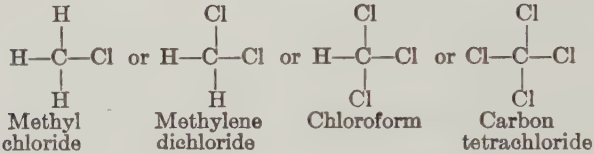
5. In most carbon compounds only one valence bond is held between adjacent carbon atoms, the other valences being satisfied by atoms of other elements, in which instances the compounds are said to be "saturated"; however, carbon atoms may hold two or three valence bonds in common, in which instances the compounds are said to be "unsaturated." The following examples illustrate the three linkages that may exist between carbon atoms:



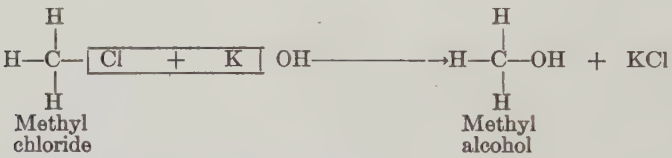
6. Different degrees of affinity for the carbon valences are exhibited. For this reason some elements will readily replace other elements attached to carbon, and this explains why so many compounds of carbon may be prepared. Thus the compound methane,



when treated with chlorine under varying conditions, will give:

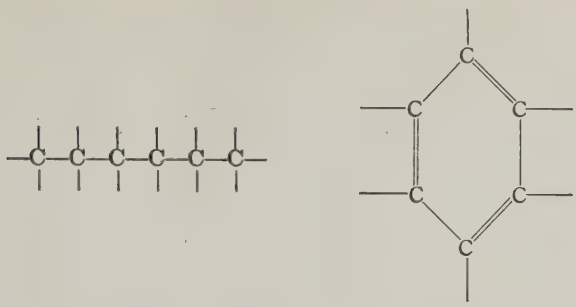


The chlorine in these compounds may be replaced by other groups of atoms:



and thus the process of replacement of one group by another may be continued indefinitely, and a very great number of compounds may be made.

Divisions of Organic Compounds.—Organic compounds are divided into two great classes: the aliphatic compounds and the aromatic compounds. The aliphatic compounds contain carbon atoms linked together in the form of open chains. The aromatic compounds are composed of carbon atoms linked together in closed rings, containing usually 5 or 6 atoms. These two main divisions are illustrated by the following skeleton formulas:



ALIPHATIC, or open chain type

AROMATIC, or closed chain type

Each of the above major divisions of organic compounds may be subdivided into 8 classes, which are as follows:

Hydrocarbons
Alcohols
Aldehydes
Ketones
Acids
Ethers
Esters
Amines

A very brief discussion of each of these general classes of organic compounds will be given.

Questions for Study

1. What is organic chemistry?
2. What was the early conception regarding organic chemistry?
3. What is the valence of carbon?
4. Is sharing or transfer of electrons by carbon the more frequent in organic reactions?
5. Why do so many organic compounds exist?
6. What are the two major divisions of organic compounds? Distinguish clearly between these two divisions.
7. Name the 8 subdivisions of organic compounds.

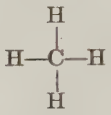
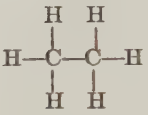
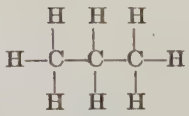
CHAPTER XXI

ORGANIC CHEMISTRY: HYDROCARBONS, ALCOHOLS, ALDEHYDES, KETONES

Aliphatic Compounds

Saturated Hydrocarbons

EXAMPLES:

NAME	MOLECULAR FORMULA	STRUCTURAL FORMULA
Methane	CH_4	
Ethane	C_2H_6	
Propane	C_3H_8	

The above substances merely introduce the subject of *hydrocarbons, which are compounds containing the elements carbon and hydrogen.* The student will see at once that each compound in the series differs from the one preceding it by CH_2, and will suspect from these examples that many more compounds can be made by adding CH_2 groups. Such is the case. This series has been found to extend up to hexacontane, which has the formula $C_{60}H_{122}$, and we do not know how far it may be continued.

Occurrence and Importance.—The first member of this series, methane, called "marsh gas" and "fire damp," arises from the decomposition of animal and vegetable matter. It is an important constituent of natural gas and artificially prepared coal gas. It is quite inflammable and has been a frequent cause of explosions in mines.

Commercially, the hydrocarbons are very important. Gasoline is a mixture of the lower members of this series; petroleum ether, benzine, kerosene, vaseline, and various lubricating oils are hydrocarbons; the mineral oils used in medicine, such as petrolatum and nujol, are mixtures of hydrocarbons. The great sources of hydrocarbons are petroleum and coal.

Preparation of Methane.—The methods of preparation of hydrocarbons for commercial purposes are fractional distillation of petroleum and distillation of coal in the absence of oxygen. In this course we will have time to consider only the preparation of methane.

Two laboratory methods for the preparation of methane are as follows:

1. Synthetic. Passing hydrogen over elementary carbon at 475° C. in the presence of a catalyst (nickel).

$$C + 2H_2 \rightarrow \underset{\text{Methane}}{CH_4}$$

2. Heating sodium acetate with soda lime (a mixture of NaOH and CaO).

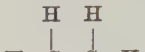
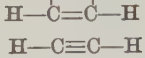
$$CH_3COONa + NaOH \rightarrow \underset{\text{Methane}}{CH_4} + Na_2CO_3$$

These methods are of importance because they show how methane is prepared in the laboratory. Methane serves as a starting material for the preparation of other hydrocarbons and a great many organic compounds.

General Properties.—The members of the hydrocarbon series containing less than 5 carbon atoms are gases; those having 5 to 16 carbon atoms are liquids; and the ones containing more than 16 carbon atoms are solids. The hydrocarbons are not active chemically. They are called paraffins because the term paraffin means "little affinity" or little activity. They are insoluble in water. They do not react with strong acids and alkalies. They burn readily, however, and react with chlorine and bromine, particularly in the sunlight.

Unsaturated Hydrocarbons

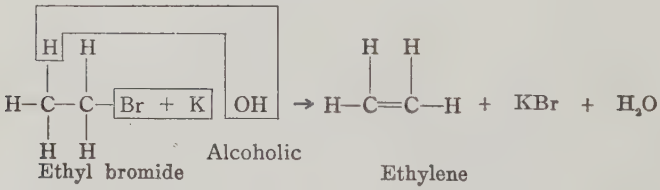
EXAMPLES:

NAME	MOLECULAR FORMULA	STRUCTURAL FORMULA
Ethylene	C_2H_4	
Acetylene	C_2H_2	

The saturated hydrocarbons may be treated by chemical procedures which will remove some of the hydrogen atoms. The resulting compounds are known as unsaturated hydrocarbons. In such compounds there are adjacent carbon atoms which hold two or three valence bonds in common.

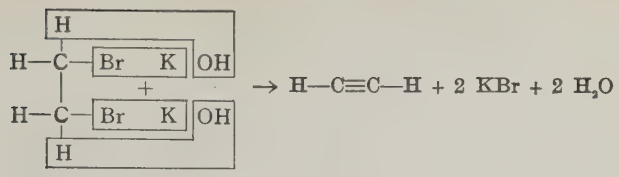
When there are two valence bonds (double bond) between adjacent carbon atoms, the compound belongs to the *olefine series.* Ethylene is the first member of the olefine series. When there are three valence bonds (triple bond) between two adjacent carbon atoms, the compound belongs to the *acetylene series.* Acetylene is the first member of this series.

Ethylene.—Ethylene is prepared by treating ethyl bromide with alcoholic potassium hydroxide.



Ethylene is a colorless, inflammable gas with a pleasant odor. It is a typical representative of the olefine series. The double bond in ethylene gives to this compound the property of being unusually reactive, a characteristic in sharp contrast with the properties of the saturated hydrocarbons.

Acetylene.—Acetylene is prepared by treating ethylene bromide with alcoholic potassium hydroxide, a reaction similar to that used in the preparation of ethylene.

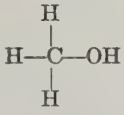
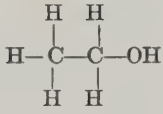
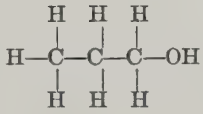


Ethylene bromide — Acetylene

Acetylene is a colorless gas. It is highly inflammable and in burning it produces a very hot flame. Acetylene is a typical representative of the acetylene series of unsaturated compounds. The presence of a triple bond in this compound makes it even more reactive than the olefines.

Alcohols

EXAMPLES:

NAME	MOLECULAR FORMULA	STRUCTURAL FORMULA	CHARACTERISTIC GROUP
Methyl alcohol	CH_4O		OH
Ethyl alcohol	C_2H_6O		OH
Propyl alcohol	C_3H_8O		OH

The alcohols are considered as derivatives of hydrocarbons in which a hydrogen is replaced by an OH group. By substituting an OH group for one hydrogen in methane, methyl alcohol is obtained. Similarly, ethyl alcohol may be derived from ethane, propyl alcohol from propane, etc., and thus a large series of alcohols may be prepared. The characteristic group in all alcohols is the hydroxyl (OH). Alcohols are

organic hydroxides, but are not bases, because they do not produce OH ions when in solution.

Methods of Preparation.—Alcohols may be prepared by a number of procedures. One general method will be given as a type procedure that may be applied to the preparation of all alcohols. *This method consists of treating a halogen derivative of a hydrocarbon with AgOH, NaOH, or KOH.*

Examples:

1. $CH_3|I + Ag|OH \rightarrow CH_3OH + AgI$
   Methyl iodide → Methyl alcohol

2. $C_2H_5|Br + Na|OH \rightarrow C_2H_5OH + NaBr$
   Ethyl bromide → Ethyl alcohol

An important commercial method for preparing ethyl alcohol is the fermentation of sugars by the enzymes of yeast.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

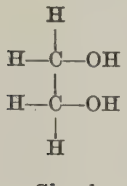
Properties and Significance.—The simpler alcohols, like methyl, ethyl, and propyl, are liquids and are readily soluble in water; the more complex ones are solids and are only slightly soluble in water. The alcohols in general have a sweet taste. They are neutral in reaction. They will burn readily, and they enter into many chemical reactions.

Ethyl alcohol, called also grain alcohol, is used commercially as a solvent for gums, resins, varnishes, perfumes, and as a reagent in the manufacture of many important articles. In medicine, ethyl alcohol is used as a vehicle for dispensing drugs, the tinctures and spirits being alcoholic solutions; and as an antiseptic and a massaging lotion. Ethyl alcohol is also an antidote for phenol, or carbolic acid, poisoning. Methyl, or wood alcohol, is used chiefly in the manufacture of organic dyes, and as a solvent for varnishes.

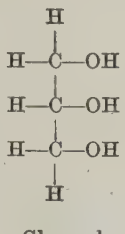
Methyl alcohol is poisonous; ethyl alcohol is toxic in large amounts; and propyl, butyl, and amyl alcohols, a mixture of which is called "fusel oil," are severely toxic.

Complex Alcohols.—There are many alcohols in nature of a much more complex character than those suggested by

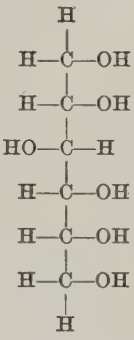
the above discussion. There are alcohols containing more than one OH group in the molecule. Examples are as follows:



Glycol



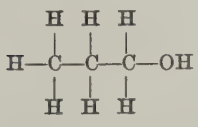
Glycerol



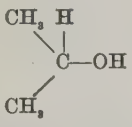
Sorbitol

Glycerol is a trihydroxy alcohol which is important because it is a constituent of fats (studied later). Sorbitol is a hexahydroxy alcohol from which simple sugars (studied later) are derived.

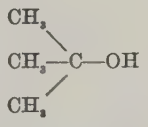
Primary, Secondary, and Tertiary Alcohols.—It is of further interest that there are three classes of alcohols, primary, secondary, and tertiary. A primary alcohol has an OH group attached to the carbon atom at the end of a carbon chain. In a secondary alcohol there are two organic radicals attached to the carbon atom holding the OH group. A tertiary alcohol contains three organic radicals attached to the carbon atom which holds the OH group. The following examples will make this clear:



Propyl alcohol (Primary)

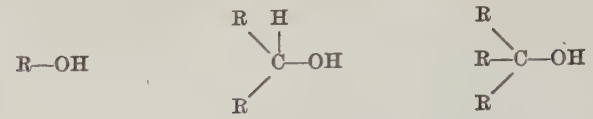


Isopropyl alcohol (Secondary)



Isobutyl alcohol (Tertiary)

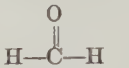
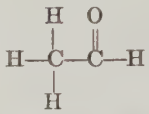
Letting R stand for any organic radical (CH_3–, C_2H_5–, C_3H_7–, etc.) we may indicate the distinction between the three classes of alcohols in a more general way as follows:



Primary alcohol Secondary alcohol Tertiary alcohol

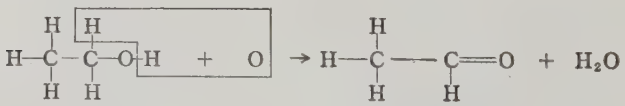
Aldehydes

EXAMPLES:

NAME	MOLECULAR FORMULA	STRUCTURAL FORMULA	CHARACTERISTIC GROUP
Formaldehyde	CH_2O		
Acetaldehyde	C_2H_4O		

The aldehydes may be regarded as derivatives of hydrocarbons in which a hydrogen atom is replaced by a *group.* It is the latter group which gives to aldehydes their characteristic properties, since the remainder of the molecule is hydrocarbon and will naturally behave like the hydrocarbons.

Preparation.—*When a primary alcohol is oxidized, an aldehyde is formed.* This is of interest not only as a general method for preparing aldehydes, but also because it calls attention to an important chemical reaction of alcohols. Thus acetaldehyde is prepared by the oxidation of ethyl alcohol.



Ethyl alcohol Acetaldehyde

Properties and Importance.—Formaldehyde and acetaldehyde are gases at room temperatures; the other aldehydes are liquids or solids. In general, the aldehydes have penetrat-

ing, suffocating odors, and as a class they are strong reducing agents.

When formaldehyde is dissolved in water to the extent of about 40 per cent, the solution obtained is known as formalin. Formalin is used as a preservative of anatomical specimens and as a disinfectant. Formalin is especially valuable for disinfecting rooms because it liberates formaldehyde gas, which does not harm clothing, is not dangerous to human beings, and, when applied correctly, penetrates all crevices or cracks in which disease-producing organisms may be present.

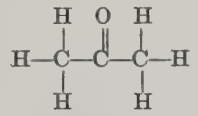
Formaldehyde condenses with ammonia to form urotropin, an important drug. Urotropin is a urinary disinfectant which is used in infections along the urinary tract, like cystitis. When ingested, it is excreted in the urine, and, if the urine is acid, it will decompose and liberate formaldehyde, which attacks the organisms causing the infection.

Acetaldehyde is important as the immediate source of paraldehyde, which is used in medicine as a sleep producer.

The aldehydes have a special importance in that their characteristic group is a significant constituent of the molecule of certain carbohydrates, substances to be studied later.

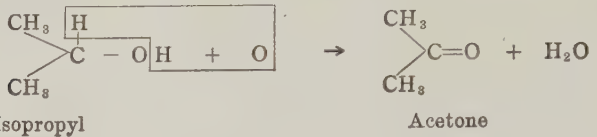
Ketones

EXAMPLE:

NAME	MOLECULAR FORMULA	STRUCTURAL FORMULA	CHARACTERISTIC GROUP
Acetone	C_3H_6O		

Ketones are important in demonstrating the structure of a group found in sugars which we will study later. The student should note that *the characteristic* *group in this series is the carbonyl radical,* —C—, *otherwise the molecule is the same as that of the hydrocarbons.*

Preparation.—*Ketones are prepared by the oxidation of secondary alcohols.* Thus isopropyl alcohol, when oxidized, yields acetone.



Isopropyl alcohol — Acetone

This is a general method. The oxidation of more complex secondary alcohols yields corresponding ketones.

Properties.—Ketones are of interest to us because they are a characteristic group of substances in organic chemistry, and certain carbohydrates (studied later) are ketones.

Acetone, the first member of the ketone series, is a colorless liquid, with a very pleasant odor. It is soluble in water. It has chemical properties resembling aldehydes in some respects. It occurs in the urine in diabetes mellitus, the significance of which we will study later. It is a good solvent for fats, gums, resins, paints, and varnishes. When mixed with benzene, it is an excellent paint remover.

Questions for Study

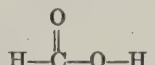
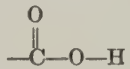
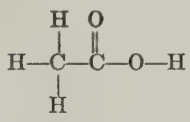
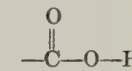
1. What are hydrocarbons? Name some important hydrocarbons.
2. Distinguish between saturated and unsaturated hydrocarbons.
3. How is methane prepared?
4. Discuss the occurrence and importance of the hydrocarbons.
5. What is meant by the paraffin series of hydrocarbons? The olefine series? The acetylene series?
6. What is the effect of the presence of double or triple valence bonds upon the properties of the compound?
7. What is an alcohol? Name four alcohols.
8. What are the uses of ethyl alcohol?
9. Give one method for the preparation of an alcohol.
10. Name three complex alcohols. What is the importance of glycerol and sorbitol?
11. Distinguish between a primary, secondary, and tertiary alcohol.
12. What is an aldehyde? Name two aldehydes.
13. What is a general method for preparing aldehydes?
14. What is formalin? What are its uses?
15. What is a ketone?
16. What is a general method for preparing ketones?
17. What is the importance of ketones?

CHAPTER XXII

ORGANIC CHEMISTRY: ORGANIC ACIDS, ESTERS, ETHERS, AMINES

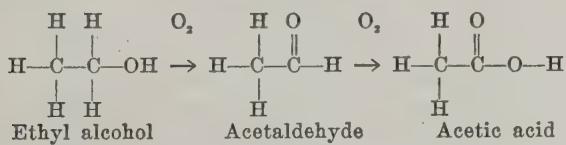
Organic Acids

EXAMPLES:

NAME	MOLECULAR FORMULA	STRUCTURAL FORMULA	CHARACTERISTIC GROUP
Formic acid	CH_2O_2		
Acetic acid	$C_2H_4O_2$		

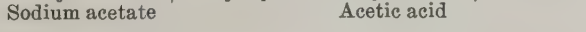
The organic acids may be considered as hydrocarbons in which one or more of the hydrogens is replaced by a COOH group. The latter group is called a "carboxyl." The carboxyl group is characteristic of all organic acids; it contains one hydrogen atom which ionizes in solution and gives acid properties to the compound. An organic acid may contain one or several COOH groups. The organic acids which contain one COOH group are called fatty acids, because many of them occur in fats.

Methods of Preparation.—1. *When a primary alcohol is mildly oxidized, an aldehyde is formed. If the aldehyde is oxidized further, an organic acid is produced.*



Ethyl alcohol — Acetaldehyde — Acetic acid

2. *Another general method is treatment of a salt of an organic acid with a strong mineral acid.*



Sodium acetate — Acetic acid

General Properties.—The organic acids which contain less than 9 carbon atoms are liquids; those containing more than 9 carbon atoms are solids. The lower members of the series are soluble in water; the higher members are insoluble. The organic acids are weak acids; that is, their molecules dissociate only slightly, yielding a relatively small number of hydrogen ions when in solution. They exhibit the general properties of the mineral acids, but not in as marked a degree, since they do not ionize to the same extent.

Formic acid, the first member of the organic acid series, occurs in ants, bees, nettles, and pine needles. The "sting" of a bee, or a nettle, is due to the irritating action of formic acid liberated under the skin. This acid may be prepared by macerating ants, or nettles, with water, and distilling the mixture. It is the strongest acid in the fatty acid series.

Acetic acid is an important by-product obtained in the dry distillation of wood, the process used to make wood charcoal. It may also be prepared by the fermentation of fruit juices which contain sugar. Vinegar is a dilute (3-6 per cent) solution of acetic acid which is usually made from the juice of the apple. In the preparation of vinegar, sugar is first converted to alcohol by a ferment in yeast called zymase; later the alcohol is oxidized to acetic acid by oxidizing bacteria (bacterium aceti) which are in the so-called "mother of vinegar." The latter occur in the air and readily get into a solution exposed to the atmosphere. Acetic acid is used in the manufacture of drugs, dyes, and paints, and is a valuable reagent in the chemical laboratory. Glacial acetic acid is acetic acid of 100 per cent concentration. A very dilute solution of acetic acid is a good antidote for a burn caused by an alkali.

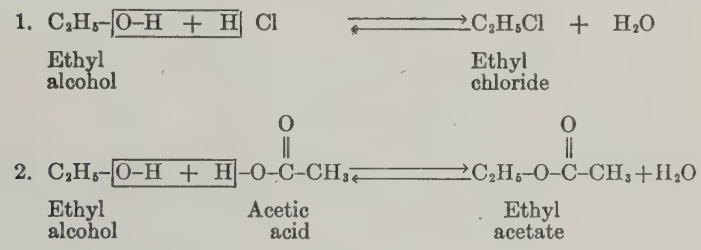
Other organic acids of importance are: lactic acid, which results from the action of bacteria upon the lactose of milk, and gives to sour milk its characteristic acid taste; butyric acid, the volatile substance giving to rancid butter its offensive odor; oxalic acid, which is valuable for cleansing purposes, such as removal of ink stains, cleaning straw hats, etc.;

citric acid, found in fruits like the lemon, lime, or grapefruit; malic acid, found in apples; and tartaric acid, found in grapes, whose salt, "cream of tartar," is used in baking powders.

The fatty acids, constituents of the fats (studied later), are also organic acids of special importance.

Esters

An ester may be regarded as an organic salt produced by the interaction of an alcohol with an acid. The formation of esters is illustrated by the following reactions:

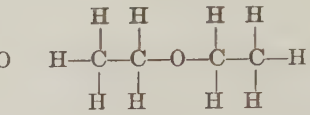


In the above reactions an ester and water are formed in each case, just as a salt and water are formed in the neutralization of an acid with a base in inorganic reactions. Ethyl chloride and ethyl acetate are typical esters; that is, they are compounds resulting from the action of acids upon an alcohol.

The esters are also called ethereal salts because they are very volatile. As a class they have a very pleasing, fruity odor. The esters are the characteristic constituents of perfumes and flavoring extracts, and are, in fact, the constituents which in many cases give to fruits and flowers their characteristic odors. They are widely distributed in nature, being found more especially in the fruits and flowers of plants. Examples of naturally occurring esters are: amyl acetate in pears; ethyl butyrate in pineapples; octyl acetate in oranges; and amyl butyrate in apricots. Amyl nitrite and ethyl nitrite are synthetic esters used in medicine to lower blood pressure.

Ethers

EXAMPLE:

NAME	MOLECULAR FORMULA	STRUCTURAL FORMULA	CHARACTERISTIC GROUP
Ethyl ether	$C_4H_{10}O$		—O—

The ethers are organic oxides. They consist of two hydrocarbon radicals joined by an atom of oxygen.

Methods of Preparation.—1. *A general method of preparing ethers consists of treating a halogen derivative of a hydrocarbon with sodium alcoholate.*

$$\underset{\text{Methyl iodide}}{CH_3|I} + \underset{\text{Sodium methylate}}{Na|OCH_3} \rightarrow \underset{\text{Methyl ether}}{CH_3—O—CH_3} + NaI$$

2. *The commercial method of preparing ethyl ether is by treating ethyl alcohol with sulfuric acid.* In this reaction, there is a removal of one molecule of water from two molecules of alcohol. The method requires specially controlled conditions with respect to amounts of sulfuric acid and ethyl alcohol used and the temperature of the reaction.

$$\underset{\text{Ethyl alcohol}}{C_2H_5O|H} + \underset{\text{Ethyl alcohol}}{HO|C_2H_5} \rightarrow \underset{\text{Ethyl ether}}{C_2H_5—O—C_2H_5} + H_2O$$

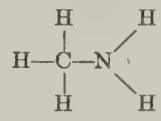
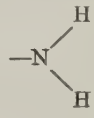
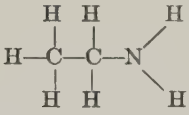
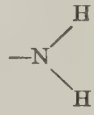
General Properties.—The ethers of lower molecular weights are colorless liquids. They are stable in the presence of strong acids and alkalies. The lower members of the series are somewhat volatile. As a class, the ethers are very inflammable.

Ethyl ether is the most important of this series of compounds because of its value as a general anesthetic. It is a colorless, volatile liquid, with a pleasant odor. *It is highly inflammable and is explosive when mixed with air and ignited. For this reason ether should never be used near a burning flame.* Ether is an excellent solvent for fats, gums, resins, and alkaloids, as well as many inorganic substances.

In 1846 ethyl ether was introduced into surgery as an anesthetic. Since that time it has been used very widely for general anesthesia because its administration can be easily regulated and it is not toxic, in the absence of heart lesions, in the amounts used to produce the surgical state of anesthesia. Aside from its combustibility, ether is an inactive substance chemically.

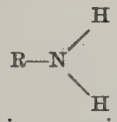
Amines

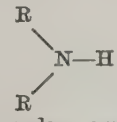
EXAMPLES:

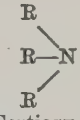
NAME	MOLECULAR FORMULA	STRUCTURAL FORMULA	CHARACTERISTIC GROUP
Methyl amine	CH_3NH_2		
Ethyl amine	$C_2H_5NH_2$		

The amines may be regarded as organic derivatives of ammonia. As shown in the above formulas, in a primary amine one hydrogen of ammonia is replaced by an organic radical. Methyl and ethyl amines are examples of primary amines. In a secondary amine two hydrogens of ammonia are replaced by organic radicals, while in tertiary amines organic radicals replace all three hydrogens in ammonia.

Letting R stand for any organic radical, we may write the formulas for primary, secondary, and tertiary amines as follows:

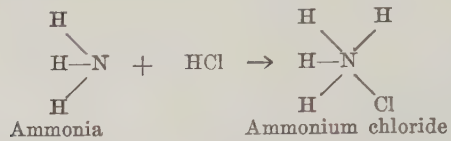

Primary amine


Secondary amine

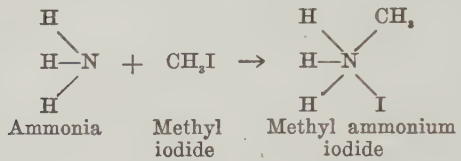

Tertiary amine

The amines are of great importance as they are related chemically to the amino acids which compose proteins. In this course we will consider only the lower members of the group of primary amines.

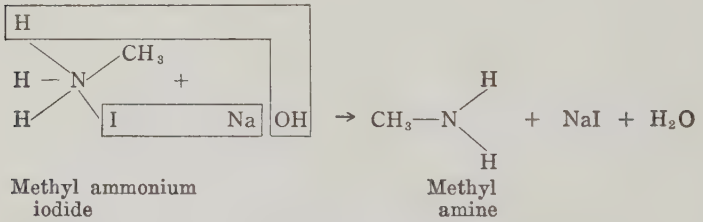
Preparation of Methyl Amine.—If ammonia is mixed with hydrogen chloride, the valence of nitrogen changes from 3 to 5, and ammonium chloride is formed.



In like manner, if ammonia is treated with methyl iodide, methyl ammonium iodide is formed.



If now the methyl ammonium iodide is treated with an alkali, methyl amine is formed.



These are typical reactions which illustrate how amines in general may be prepared.

Properties.—The lower members of the primary amine series are soluble in water and form solutions more basic than ammonia. Their vapors have a strong fishlike odor and are inflammable. The higher members of the group are insoluble in water and are odorless.

Most of the amines are poisonous to the body. Meats and other protein foods sometimes become contaminated with bacteria which attack the proteins and produce amine-like substances called "ptomaines." The ingestion of the latter results in the condition known as "ptomaine poisoning."

Toxic amines are also produced in greater or less quantities by bacterial action upon proteins in the intestinal tract. When absorbed into the blood, these substances affect blood pressure, produce headaches, and have a generally undesirable effect upon the body.

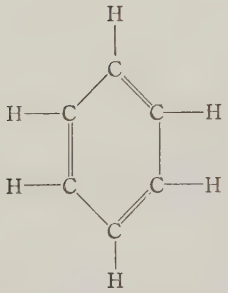
Questions for Study

1. What is an organic acid?
2. Compare the properties of organic acids with those of inorganic acids.
3. How is acetic acid prepared?
4. Name five organic acids of importance.
5. What are esters?
6. How are esters prepared?
7. What is an ether?
8. What are the properties and uses of ethyl ether? What precaution is necessary in using ethyl ether?
9. What is an amine?
10. What is the importance of the amines?
11. Distinguish between primary, secondary, and tertiary amines.
12. What are the general properties of the lower members of the amine series?
13. Discuss the toxicity of amines.

CHAPTER XXIII

ORGANIC CHEMISTRY: AROMATIC COMPOUNDS

Benzene

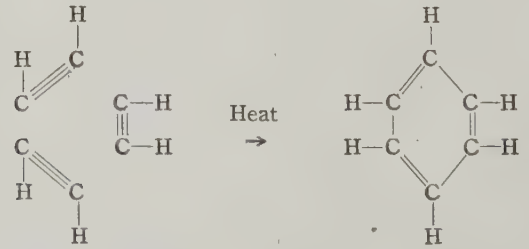


Structural formula

Abbreviated structural formula

Benzene is the parent substance of the great class of organic compounds known as the *aromatic compounds.* Using benzene as the starting point, most of the other aromatic compounds may be prepared, just as methane may be used to start the preparation of the aliphatic compounds

Preparation of Benzene.—Benzene is made by heating acetylene. The preparation is accomplished practically by passing the acetylene through a red hot tube. It may be represented as follows:

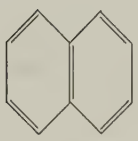


Acetylene (3 molecules)

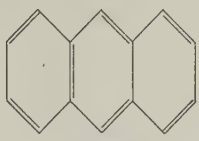
Benzene

This method is of great importance because it shows how the chemist may prepare an aromatic (ring structure) compound from an aliphatic (straight chain) compound.

Benzene Derivatives

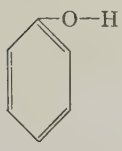


Naphthalene

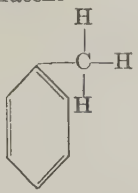


Anthracene

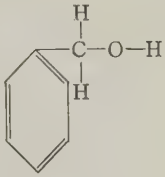
Diphenyl



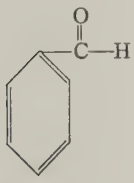
Hydroxy-benzene or Phenol



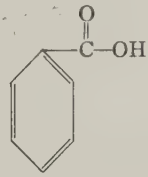
Methyl benzene or Toluene



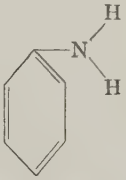
Benzyl alcohol



Benzaldehyde



Benzoic acid



Aminobenzene or Aniline

Looking at the structural formula for benzene, the student will see that many other compounds can be made from this substance by substituting groups of atoms for one or several of the hydrogens in the ring, and by joining benzene rings together. From the above examples, it will be noted that the same general classes found in the aliphatic division, such as alcohols, aldehydes, acids, amines, etc., exist in the aromatic division, the essential difference being the presence of one or more closed rings of carbon atoms in the molecule. There is also a great deal of similarity in the chemical reactions of the aliphatic and aromatic compounds.

The great source of these compounds is coal tar, which is obtained as a by-product in the manufacture of illuminat-

ing gas. In the modern gas plant, coal is heated in closed retorts out of contact with air. By this process coke is formed and coal gas is liberated, which is stored in tanks and later used for fuel or for illuminating purposes. In this procedure considerable volatile matter condenses, while the gases pass through cooling pipes, and forms "gas liquor," or coal tar. From coal tar thousands of very useful organic compounds, such as drugs, dyes, explosives, etc., are prepared.

Questions for Study

1. What are aromatic compounds?
2. What is the importance of benzene?
3. How is benzene prepared? What is the theoretical importance of this method?
4. Name some benzene derivatives.
5. What is the great natural source of aromatic compounds?

UNIT XI

CARBOHYDRATES, PROTEINS AND FATS

CHAPTER XXIV

CARBOHYDRATES

Occurrence.—Carbohydrates are a very important class of organic compounds, of which the sugars, starch, cellulose, and glycogen are typical representatives. They are distinctly peculiar to plant life, being produced by, and found chiefly in, plant tissues. The woody, or fibrous, part of the plant is composed principally of cellulose, and the foods stored by plants in their roots, seeds, and fruits are to a large extent some form of carbohydrate. A small amount of carbohydrate is present in the tissues of animals.

Definition.—Carbohydrates are organic compounds composed of carbon, hydrogen, and oxygen. The carbohydrate molecule contains either an aldehyde or a ketone group and also a number of alcoholic OH groups. Carbohydrates are, therefore, *aldehyde or ketone derivatives of polyhydroxy alcohols.* A carbohydrate containing an aldehyde group is called an aldose; one containing a ketone group is called a ketose.

Origin.—Carbohydrates are produced in Nature by plants. *Plants take up carbon dioxide from the air and water from the soil, and, by means of the energy obtained from sunlight, combine these two substances to form carbohydrates. This process is called photosynthesis. Chlorophyll, the green coloring matter in the leaves of plants, is necessary for photosynthesis; it makes available for this process the energy in the sun's rays.* The energy stored by plants in the form of carbohydrates thus originates from the sun.

Carbon Cycle in Nature.—The ability of animals to form carbohydrates from amino acids, or other sources, is limited.

Consequently animals depend to a considerable extent upon plants for foods containing carbohydrates. On the other hand, plants use carbon dioxide, a waste product of animals, for the synthesis of carbohydrates, and are, therefore, benefited by animals. Animal life is thus dependent upon plant life for existence; plants in turn derive certain benefits from animals. This mutually beneficial cycle is shown by the following equations:

Process Carried Out by Plants (Photosynthesis):

$$\underset{\text{From air}}{6\ CO_2} + \underset{\text{From soil}}{6\ H_2O} \xrightarrow[\text{and chlorophyll}]{\text{Sunlight}} \underset{\text{Simple sugar}}{C_6H_{12}O_6} + \underset{\text{Returned to air}}{6\ O_2}$$

Part Played by Animals:

$$\underset{\text{Sugar ingested and absorbed into tissues}}{C_6H_{12}O_6} + \underset{\text{Taken from air}}{6\ O_2} \rightarrow \underset{\text{Expired through lungs}}{6\ CO_2} + \underset{\text{Returned to soil and air}}{6\ H_2O}$$

The first equation above shows that plants use carbon dioxide from the air and water from the soil to produce simple sugars, sunlight and chlorophyll being necessary to make this reaction take place. Plants also release oxygen into the air; this is the mechanism by which the oxygen content of the air is kept constant. The second equation indicates that the sugars (or carbohydrates) produced by plants are used by animals as food; and that animals return carbon dioxide to the air, and water to the air and the soil. In this connection it is to be noted that carbon dioxide and water are the same substances that were used by plants (as shown in the first equation) to form carbohydrates. These two equations, therefore, show that the relationship between plants and animals, with reference to carbon, hydrogen, and oxygen, is a closed cycle, and that each of these two great classes of living things produces that which is necessary for the maintenance of the other. This relationship between plants and animals is known as the carbon cycle in nature.

Nomenclature.—Carbohydrates get their name from the fact that in this class of compounds hydrogen and oxygen

are usually found in the same ratio as they occur in water (H_2:O). They might, therefore, be considered as hydrates of carbon, or more simply, carbohydrates. This plan for naming these substances, however, cannot be taken as the basis of a definition because there are exceptions to the H_2:O ratio.

Classification.—Carbohydrates are classified upon the basis of the number of saccharide groups in their molecules. The carbohydrate classification includes monosaccharides, disaccharides, trisaccharides, tetrasaccharides and polysaccharides. Monosaccharides, or simple sugars, contain one saccharide group in their molecule (prefix *mono* means one). The monosaccharides of principal interest in this course are hexoses ($C_6H_{12}O_6$). Other carbohydrates classified under the monosaccharide group are bioses, trioses, tetroses, pentoses and heptoses, substances containing 2, 3, 4, 5 and 7 carbon atoms, respectively, in the molecule. The disaccharides, trisaccharides, tetrasaccharides and polysaccharides contain 2, 3, 4 and many saccharide units, respectively, in the molecule. The more important carbohydrates are included in the accompanying table of classification (Table IX).

TABLE IX

NAME OF CLASS	EXAMPLES	FORMULA
Monosaccharides	Glucose Fructose Galactose	$C_6H_{12}O_6$
Disaccharides	Sucrose Maltose Lactose	$C_{12}H_{22}O_{11}$
Polysaccharides	Starch Dextrin Glycogen Inulin Cellulose Agar Pectin	$(C_6H_{10}O_5)_x.H_2O$

Structure.—The following graphic formulas for glucose and fructose will serve to illustrate the structure of mono-

PLATE II.—THE CARBON CYCLE IN NATURE.

The beautiful garden in the photograph on the opposite page presents interesting examples of the carbon exchanges that take place in Nature. Plants take up carbon dioxide from the air and water from the soil, and in the presence of sunlight, produce complex carbon compounds, many of which are used by animals as food. Animals ingest carbon-containing foods and as a result of their metabolic processes excrete carbon dioxide into the air. Carbon dioxide is also returned to the air through the decay of dead plants and animals, and from the burning of wood, coal, or other fuel products originally formed by plants. Thus there is a continuous cycle of carbon in Nature. (Reproduced from the National Geographic Magazine 75: Plate XV, March, 1939, with special permission.)

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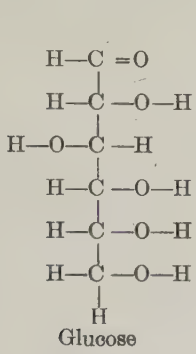
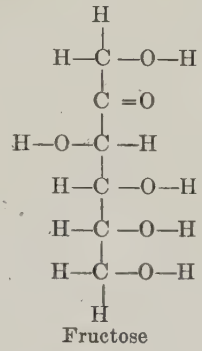
Kodachrome Photograph by B. Anthony Stewart

PLATE II.—See opposite page for legend.

saccharides, glucose being a simple aldose sugar, and fructose a simple ketose sugar:



Glucose



Fructose

These formulas show the two representative types of structure that are found in all carbohydrates. They illustrate the fact that carbohydrates are groups of hydrogen and oxygen atoms, arranged around central carbon atoms; that there is either an aldehyde group, or a ketone group, in the molecule; and that alcoholic groups are present in every case.

Disaccharides are composed of two molecules of monosaccharides linked together. Sucrose is made up of one molecule of glucose and one molecule of fructose; maltose is composed of two molecules of glucose; and lactose contains one molecule of glucose and one of galactose.

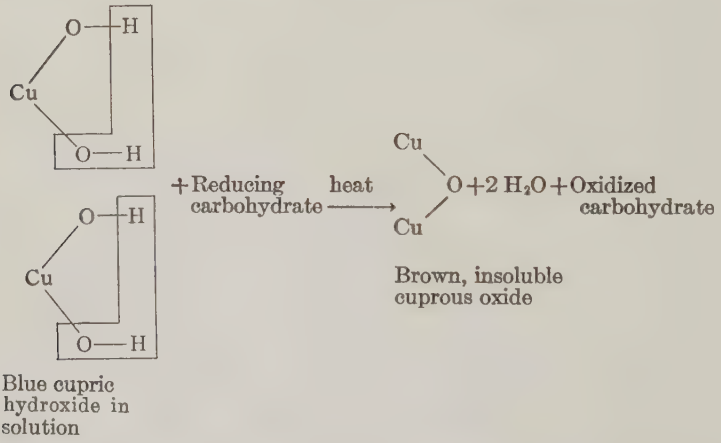
The polysaccharides are composed of many molecules of monosaccharides. Starch is believed to be composed of 26 to 30 molecules of glucose; glycogen contains probably 12 molecules of glucose; cellulose contains about 200 glucose units; and the inulin molecule probably consists of 30 units of fructose.

Physical Properties.—The monosaccharides and disaccharides are crystalline solids. They are soluble in water. The polysaccharides are amorphous substances of varying solubilities. The dextrins and glycogen are soluble in cold water; starch, inulin, and agar are soluble in hot water; and cellulose is highly insoluble in water. The polysaccharides, which can be dissolved, form colloidal solutions.

Chemical Properties.—

1. *Stability.*—The stability of carbohydrates is greatest in a neutral medium. They decompose slightly in acids, and in general are unstable in alkalies. Sugars readily "caramelize" in an alkaline solution.

2. *Reducing Substances; Fehling's and Benedict's Tests.*—Carbohydrates either are reducing agents, or will form reducing substances when boiled with dilute acids or alkalies. Some carbohydrates have the power to reduce alkaline metallic oxides, and this property is the basis of Fehling's, Benedict's and other tests for sugars. Fehling's and Benedict's reagents are alkaline copper sulfate solutions. They are blue in color. When these reagents are heated with a few drops of a simple sugar solution, the blue color fades, or disappears entirely, and a reddish brown precipitate of cuprous oxide is formed. This reaction is illustrated by the following equation:



This is the standard test for sugar in urine. The appearance of reddish brown cuprous oxide, when a few drops of urine are heated with Fehling's or Benedict's reagent, is a positive indication of the presence of sugar, since sugar is the only reducing substance that occurs in appreciable amounts in the urine. All monosaccharides and all disaccharides, except sucrose, reduce Fehling's and Benedict's solutions.

3. *Fermentation.*—Carbohydrates undergo a chemical change known as fermentation in the presence of enzymes secreted by certain microorganisms. Fermentation is a somewhat general term, and means, broadly speaking, a chemical decomposition with the evolution of gas. The products formed in the fermentation of carbohydrates vary according to the organisms which produce the reaction. The simple sugars undergo a fermentation when treated with yeast. The fermentation of sugars by yeast is known as alcoholic fermentation, since alcohol and carbon dioxide are the products formed. This reaction is brought about by the action of an enzyme, called zymase, which is secreted by yeast. It may be represented as follows:

$$\underset{\text{Sugar}}{C_6H_{12}O_6} \xrightarrow{\text{Zymase}} \underset{\text{Ethyl alcohol}}{2\ C_2H_5OH} + \underset{\text{Carbon dioxide}}{2\ CO_2}$$

Alcoholic fermentation is used commercially in making wines, beers, and other alcoholic beverages.

Excessive fermentation of carbohydrates sometimes occurs in the alimentary tract through the action of enzymes secreted by bacteria, with the production of gases that are distressing and sometimes serious in their consequences. This may take place in the stomach when there is little or no free hydrochloric acid in the gastric juice. Ordinarily, the normal secretion of hydrochloric acid in the stomach acts as a disinfectant: it destroys most of the bacteria which are ingested with food. But in conditions where there is little acid secreted, bacteria will multiply in the stomach and will bring about a fermentation of sugars with gas production. Fermentation of carbohydrates also occurs in the intestines, and is most marked when excess carbohydrate is present in the diet.

4. *Hydrolysis.*—When boiled with dilute acids, or treated with certain enzymes, the polysaccharides and the disaccharides are hydrolyzed to monosaccharides. This reaction is represented by the following equation, showing the hydrolysis of a disaccharide:

$$\underset{\text{Disaccharide}}{C_{12}H_{22}O_{11}} + H_2O \rightarrow \underset{\text{2 Monosaccharides}}{2\ C_6H_{12}O_6}$$

5. *Oxidation.*—When oxidized completely, carbohydrates yield carbon dioxide and water, and liberate considerable heat. Thus

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{Heat}$$

When burned, either in the laboratory or in the human body, carbohydrates have an average heat value of 4 Calories per gram.

Individual Occurrence, Importance, and Uses of Principal Carbohydrates

Glucose

Glucose is an important monosaccharide. It occurs free in the juices of fruits, and in the sap of some plants. Combined with itself, or with other monosaccharides, it is a constituent of maltose, sucrose, lactose, starch, and cellulose. Glucose is the principal constituent of the commercial syrups, such as corn syrup. The sugar in the blood of animals is glucose. Glucose is also called dextrose and grape sugar.

Fructose

Fructose is found free in the sap of many plants, in fruit juices, and in honey. It is also a constituent of sucrose and inulin. It is a very sweet sugar, being much sweeter than glucose. Fructose is also called levulose.

Galactose

Galactose is a constituent of lactose and of certain compounds in nerve tissue.

Sucrose

Sucrose occurs in sugar cane, sugar beet, and sugar maple, and also in certain fruits. It is the ordinary table sugar of commerce, and is commercially the most important disaccharide, being used in enormous quantities as a food. It is a very sweet sugar. Sucrose is also called saccharose and cane sugar.

Lactose

Lactose occurs in milk. It is synthesized in the mammary glands of mammals from the sugar of their blood. It occurs in cow's milk to the extent of 4 to 5 per cent, and in human milk in amounts ranging from 6 to 8 per cent. It sometimes occurs in the urine of pregnant women. It is not found in plants.

Maltose

Maltose is an intermediate product in the hydrolysis of starch and dextrins. It may be prepared from the latter substances by boiling them with dilute acids, or by treating them with digestive enzymes, such as ptyalin of the saliva.

Starch

Starch is found in the seeds, tubers, fruits, and leaves of plants. It is deposited in plant tissues in granules of characteristic shape. It is a food substance of enormous importance, and is the source of the dextrins, maltose, and commercial glucose preparations.

Dextrins

The dextrins are intermediate products of the hydrolysis of starch to maltose. In addition to the methods involving hydrolysis, dextrins may be prepared from starch by heating the latter substance to 210° C. They are colloidal substances and their chief use is as mucilages.

Inulin

Inulin occurs in the tubers of dahlias and in the Jerusalem artichoke. As inulin is not digestible, it has been used to supplement the diet of diabetics, since it satisfies the craving of these individuals for food and does not elevate their blood sugar.

Cellulose

Cellulose is the chief constituent of the walls of plant cells. It is a tough resistant substance that gives to plant tissues

considerable rigidity. It thus serves the important function in the plant world of being a structural or supporting substance. Wood, paper, cotton, flax, and hemp are composed principally of cellulose. Cellulose is not digested by the enzymes of the alimentary tract of man, but is a desirable constituent of the diet because it gives bulk to the feces and thus tends to prevent constipation.

Glycogen

Glycogen is the form of carbohydrate that is stored in the tissues of animals. It is found in the greatest quantities in the liver and the muscles. It is important in being a reserve food supply in the animal body. Glycogen is sometimes called animal starch.

Agar

Agar is prepared from seaweed. It is used in medicine in the treatment of constipation, since it is not digestible and will swell from the absorption of water, thus giving bulk to the feces. Agar is also used extensively in bacteriological laboratories in the preparation of culture media for growing bacteria.

Pectin

Pectin is useful as the agent which brings about the "setting" of fruit jellies. It occurs in fruits, such as apples, lemons, oranges, and grapefruit, and in certain plants. It is prepared upon a commercial basis from apple pomace and from lemon residues at citrus by-product factories. One important commercial pectin preparation is sold under the trade name of "Certo."

Carbohydrates in General

In general, the carbohydrates are a very important class of food substances. Of those mentioned in the foregoing outline, all are digestible and assimilable in the human body except inulin, agar, and cellulose. Whether pectin is assimilable is not known.

Questions for Study

1. Discuss the occurrence of carbohydrates.
2. Give a definition of carbohydrates.
3. What is the origin of carbohydrates? What is photosynthesis?
4. Describe the carbon cycle in nature. What is its importance?
5. How are the amounts of oxygen and carbon dioxide in the air kept at practically constant values?
6. How do carbohydrates get their name?
7. Give a classification of carbohydrates.
8. Mention several properties of carbohydrates.
9. Explain Fehling's test for sugar.
10. What is fermentation? Explain how fermentation occurs in the alimentary tract.
11. What are formed when disaccharides and polysaccharides are hydrolyzed?
12. What are the products of complete oxidation of carbohydrates? How much energy is liberated by the oxidation of carbohydrates?
13. Name the principal carbohydrates.
14. Give the occurrence and importance of the following: glucose, sucrose, lactose, starch, cellulose, glycogen, agar, pectin.
15. What carbohydrates are not digested and assimilated by the human body?

CHAPTER XXV

PROTEINS

The name protein comes from a Greek word meaning "to be first." Proteins are "first" in the sense that they are fundamental constituents of living matter. Every living cell contains proteins and requires a continuous supply of protein food for its existence. Proteins are, therefore, constituents of first importance to all living things.

Occurrence.—Proteins occur in Nature in living matter or associated with living things. They constitute practically all of the solid matter of the tissues of animals. Thus most of the solid matter of muscle, tendon, ligament, cartilage, and blood is composed of proteins; and about one-half of the solid substance of brain and nerve tissues, and of bone, is protein in composition. In plants proteins are subordinate to carbohydrates as structural materials, cellulose being the chief structural substance of the plant. However, proteins are essential constituents of all plant tissues; and they occur in large quantities as storage substances in the seeds and fruits of plants. Examples of plant products of a high protein content are nuts, wheat, corn, oats, beans, and peas.

Origin.—Proteins are produced in Nature always by living matter and chiefly by plants. Animals may eat proteins and transform them into other types of protein, but animals have limited powers to synthesize proteins. As will be shown later, a considerable number of the building stones of proteins cannot be synthesized by animals and animals must obtain these building stones from plant sources. Plants are, therefore, the primary protein producers of Nature. In the synthesis of proteins, plants probably form carbohydrates first and then combine simple carbohydrate units with ammonia, or other nitrogen compounds obtained from the soil, to produce the various types of proteins.

Chemical Nature of Proteins.—Proteins are organic compounds containing carbon, hydrogen, oxygen, and nitrogen.

Sulfur and iodine are also elementary constituents of some proteins. The elementary composition of proteins is approximately as follows:

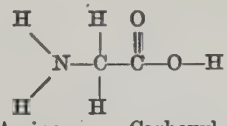
Carbon	52 per cent
Hydrogen	7 per cent
Oxygen	23 per cent
Nitrogen	16 per cent
Sulfur	0 to 3 per cent
Iodine	0 to 0.8 per cent

The protein molecule is exceedingly large. This is indicated by the following formula for oxyhemoglobin:

$$(C_{758}H_{1181}N_{207}S_2FeO_{210})_x$$

The x probably equals 4. This means that the molecular weight of oxyhemoglobin is around 68,000. The molecular weights of proteins in general range from 17,600 to 43,000,000. The student will get the significance of these figures by comparing them with the molecular weight of cane sugar, which is 342; or of glucose, which is 180; or of sodium chloride, which is 58.5.

The "building stones," or structural units, of which proteins are composed, are amino acids. There are about twenty-six different amino acids known to exist in the various proteins. The simplest of these amino acids is glycine, or aminoacetic acid, which has the following formula:



GLYCINE,
or Aminoacetic acid

Glycine is typical of all amino acids. All amino acids contain amino and carboxyl groups in their molecules. They differ from glycine principally in that they contain more atoms in their molecules; they have a slightly different arrangement of their atoms; three of them contain sulfur and

two contain iodine. They are soluble in water and some of them have a sweet taste.

With this preliminary description of amino acids, we shall proceed to define proteins. *Proteins are compounds composed of carbon, hydrogen, oxygen, and nitrogen, and sometimes sulfur or iodine. Structurally their molecules consist of amino acids joined together chiefly by union of amino with carboxyl groups.* The average number of amino acids found in the molecules of proteins is about 288. The differences in the many proteins found in Nature are to be ascribed to a variation in the number, kind, and arrangement of the amino acids in their molecules.

Proteins are thus seen to be very complex substances, and we cannot hope to go very deeply into a study of their chemistry in a course of this kind. The above discussion, however, should impress the student with the facts *that the protein molecule is very large; that the fundamental units of structure, of which it is composed, are amino acids, just as monosaccharides are the building stones, or structural units, of which the molecules of carbohydrates are constructed.*

Properties of Proteins.—

1. *Solubility.*—Proteins vary widely in their solubilities. Some are readily soluble in water as, for example, the albumins of the blood; others are soluble in dilute salt solutions, or in dilute acids and alkalies, or in 70 per cent alcohol; and some are highly insoluble in water and other solvents as, for example, the albuminoids of the skin, hair, and nails.

2. *Large Molecules.*—As already stated, proteins have very large molecules. They will form colloidal solutions when dissolved in water.

3. *Reaction.*—Proteins are amphoteric; that is, they have both acid and basic characteristics. A protein will react with either an acid or a base, forming a protein salt. This behavior is due to the fact that the protein molecule contains both amino (NH_2) and carboxyl (COOH) groups. Amino groups, being ammonia derivatives, have basic properties; carboxyl groups contain ionizable hydrogen and are, therefore, acid in character.

4. *Precipitation by Heavy Metals.*—Proteins are precipitated from solution by the ions of some of the heavy metals, like mercury, lead, and silver. This is the reaction that takes place if bichloride of mercury is swallowed. When bichloride of mercury is swallowed, the mercury ions of this compound combine with the proteins of the mouth, esophagus, and stomach, and precipitate them from solution. In this manner a local destruction of tissue is produced. If the mercury is left in the alimentary tract, it is slowly absorbed into the blood and carried by the latter to the various internal organs and finally to the kidneys. It has a destructive action upon all the tissues of the body since all tissues contain proteins. Its most serious effect upon the body is its action upon the kidneys, because the inflammation it produces in these organs interferes so extensively with their excretory function.

The antidote for mercury poisoning is some form of protein, like milk, eggs, and cheese. The use of eggs, milk, and cheese is based upon the fact that these substances will react with mercury and precipitate it from solution; in this manner they substitute themselves for the proteins of the walls of the stomach, and thus protect the latter from the destructive action of this poison. A stomach tube is always introduced, and the contents of the stomach are removed as soon as possible in case of mercury poisoning, even though an antidote has been used. It is important to remove the eggs and milk which have served as antidotes; otherwise they will be digested and release the mercury, which will then be absorbed and attack the body tissues.

This reaction also explains why bichloride of mercury and silver nitrate are good disinfectants. These substances combine with the proteins of bacteria, forming insoluble precipitates, and in this manner kill bacteria.

5. *Coagulation.*—Many proteins are coagulated by heat and by alcohol; that is, they are converted into an insoluble state by these agents. Coagulation is not very well understood chemically, and for our purposes we will consider it as meaning the insoluble state of a protein which is produced by heating or by alcohol.

TABLE X

CLASSIFICATION OF PROTEINS

DIVISION	SUBDIVISION	CHIEF CHARACTERISTICS (BASIS OF CLASSIFICATION)	EXAMPLES
SIMPLE PROTEINS	Albumins	*Soluble in water.*	Egg albumin, serum albumin.
	Globulins	Insoluble in water; *soluble in dilute salt solutions.*	Serum globulin, edestin of hempseed.
	Glutelins	Insoluble in water or salt solutions; *soluble in dilute acids and alkalies.*	Glutenin of wheat.
	Prolamins	Insoluble in water; *soluble in 70 per cent alcohol.*	Gliadin and zein of grains.
	Albuminoids	Insoluble in water, salt solution, dilute acids or alkalies; hence, *highly insoluble.*	Keratin of the nails and hair.
	Histones	Soluble in water and dilute acids; *strongly basic and insoluble in ammonia.*	Globin of hemoglobin.
	Protamines	*Strongly basic protein, soluble in water. Relatively small molecule.*	Sturin, salmin, clupein, of fish's sperm.
CONJUGATED PROTEINS	Nucleoproteins	*Compounds containing protein combined with nucleic acid.*	Nuclein of the nucleus of cells.
	Glycoproteins	*Compounds containing protein combined with a carbohydrate group.*	Mucin of saliva.
	Phosphoproteins	*Compounds containing protein combined with a phosphate group.*	Casein of milk.
	Chromoproteins	*Compounds containing protein combined with a chromogenic (color-producing) nucleus.*	Hemoglobin of blood.
	Lecithoproteins	*Compounds containing protein combined with lecithin.*	Fibrinogen of tissues.

TABLE X—CONT'D

DIVISION	SUBDIVISION	CHIEF CHARACTERISTICS (BASIS OF CLASSIFICATION)	EXAMPLES
DERIVED PROTEINS	Proteans	*The first hydrolytic products of the action of water, acids, or enzymes.*	Edestan.
	Metaproteins	*Further hydrolytic products of the action of acids or alkalies.*	Acid metaprotein; alkali metaprotein.
	Coagulated proteins	*Insoluble products of the action of heat or alcohol.*	.....
	Proteoses	Products of hydrolysis of proteins; soluble in water; *precipitated by saturated ammonium sulfate solution; very slightly diffusible.*	.....
	Peptones	Products of further hydrolysis of proteins; soluble in water; *not precipitated by saturated ammonium sulfate; readily diffusible.*	.....
	Peptids	Products of further hydrolysis of proteins; soluble in water; *smaller molecule than peptones; consist of two or more amino acids linked together; more diffusible than peptones.*	.....

6. *Hydrolysis.*—When boiled with dilute acids or alkalies, or treated with digestive enzymes, proteins are hydrolyzed to amino acids. The digestion of proteins in the human body is a series of hydrolyses in which enzymes play a very important part.

7. *Oxidation.*—When proteins are treated with vigorous oxidizing reagents, the carbon of their molecules is oxidized to carbon dioxide, the hydrogen is oxidized to water, and the nitrogen is oxidized to nitrates. The same end products are formed in the oxidation of proteins or amino acids in the body, except those obtained from nitrogen. Oxidation in the body is too mild to oxidize nitrogen, consequently this element retains its reduced form during physiological oxidations and appears in the body excretions principally as urea,

or ammonium salts. The oxidation of proteins is attended by the liberation of considerable heat.

8. *Color Tests.*—When treated with appropriate reagents, proteins yield certain colors, which are the basis of laboratory tests for these substances. The principal protein color tests used to identify the proteins are as follows:

(a) Biuret Test. When a protein solution is treated with dilute alkali and very dilute copper sulfate solution, a pink to violet color is produced.

(b) Millon's Test. Millon's reagent is a mixture of mercuric nitrate and mercuric nitrite, dissolved in nitric acid. When this reagent is mixed with a protein, a white precipitate is first produced, which turns pink upon being boiled gently.

(c) Xanthoproteic Test. When treated with nitric acid, proteins turn yellow in color. This color changes to a deep brown when a little alkali is added. A xanthoproteic test upon the proteins of the skin is often performed by the student in the laboratory when nitric acid is spilled upon the hands.

(d) Hopkins-Cole Test. When glyoxylic acid (Hopkins-Cole reagent) and concentrated sulfuric acid are added to a solution of a protein, a pink color is produced.

Classification of Proteins.—There are three major classes of proteins, namely, simple proteins, conjugated proteins, and derived proteins. Each of these major groups contains several subdivisions. A classification of proteins is given in Table X, pages 242 and 243.

Functions of Proteins.—

1. *Tissue Builders.*—Proteins are the great tissue builders of the human body and the bodies of animals in general. The body selects from the proteins eaten amino acids that are appropriate for tissue construction and builds them into proteins characteristic of its own tissues. In the adult, proteins are used chiefly to renew the tissues which are constantly being broken down by the wear and tear processes of the body; in the young, proteins contribute to growth as well as to the repair of the body.

2. *Energy Production.*—Proteins are also an important source of energy. The body oxidizes all protein that is in excess of the amount necessary for tissue construction, and thus obtains considerable energy from this food substance. One gram of protein yields 4 Calories of heat when oxidized in the human body.

Questions for Study

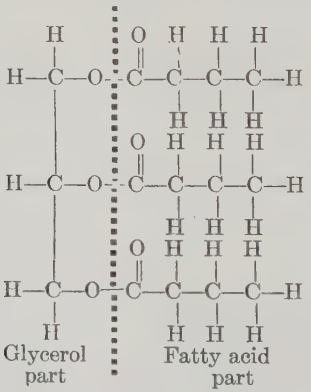
1. What is the importance of proteins?
2. Discuss fully the occurrence of proteins.
3. What is the origin of proteins in nature?
4. What elements are found in proteins? Give a definition of proteins.
5. Discuss the size of the protein molecule. How does the molecular weight of proteins compare with that of other substances?
6. Mention several properties of proteins.
7. Explain how proteins are amphoteric.
8. Describe the action of bichloride of mercury in a case of poisoning by this substance. What are antidotes for bichloride of mercury poisoning? Explain the action of antidotes for mercury poisoning.
9. How does bichloride of mercury kill bacteria?
10. What are the final products of the hydrolysis of proteins?
11. How would you test for proteins in the laboratory?
12. Explain the yellow color produced on the skin when nitric acid is spilled upon it.
13. Name the three principal classes of proteins.
14. What are the functions of proteins?
15. What is the caloric value of proteins?

CHAPTER XXVI

FATS

Occurrence.—Fats belong to a large group of substances called lipids, which are found in both plants and animals. In the human body all the cells contain small amounts of fat, and there are certain tissues, known as "fat depots," that are specialized to store fats. The fat depots of the body are the subcutaneous tissues, the tissues around the intestines and the kidneys, and the bone marrow; these tissues may contain as much as 90 per cent of fatty substances. In plants fats have an occurrence somewhat similar to that found in animals. All plant cells contain small amounts of fatty material, and plants also store large quantities of fats in their seeds, roots, and fruits. Cottonseed, castor beans, peanuts, and olives are examples of storage products of plants that have a high fat content. Both plants and animals have the power to synthesize fats, and they apparently produce them from carbohydrates.

Definition and Structure.—Fats are organic compounds composed of carbon, hydrogen, and oxygen. *They are esters*



Butyrin

of glycerol and fatty acids; that is, they are compounds produced by the reaction of glycerol with fatty acids. Glycerol,

also called glycerin, is an alcohol, containing three OH groups. The fatty acids are organic acids containing one COOH group. The preceding graphic formula for butyrin, the glyceryl ester of butyric acid, is typical of all fats.

The glycerol radical is a constituent of all fats. The differences in the many fats found in Nature are due to a variation in the fatty acids that enter into their composition. There are about thirty fatty acids entering into the composition of the fats found in Nature. The following are the most important:

FATTY ACID	FORMULA	FAT DERIVATIVE
Butyric	C_3H_7COOH	Butyrin
Caproic	$C_5H_{11}COOH$	Caproin
Caprylic	$C_7H_{15}COOH$	Caprylin
Capric	$C_9H_{19}COOH$	Caprin
Lauric	$C_{11}H_{23}COOH$	Laurin
Myristic	$C_{13}H_{27}COOH$	Myristin
Palmitic	$C_{15}H_{31}COOH$	Palmitin
Stearic	$C_{17}H_{35}COOH$	Stearin
Oleic	$C_{17}H_{33}COOH$	Olein

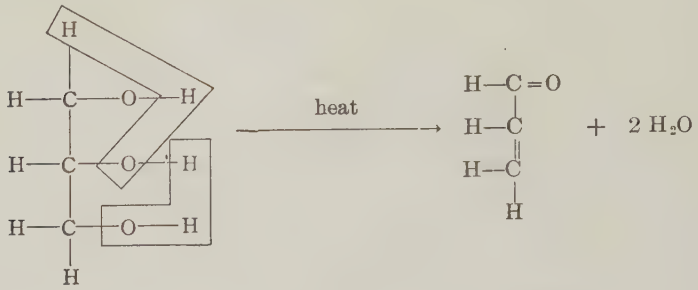
Fats are named after the fatty acid in their molecule. For example, a fat containing butyric acid in its molecule is called butyrin; one containing stearic acid is called stearin; one containing oleic acid is called olein, and so on.

Physical Properties.—When pure, fats are colorless, odorless and tasteless. The yellow color of many naturally occurring fats is due to the presence of pigments, such as carotene or xanthophyll. In general, the fats have a "greasy" feel, and are insoluble in water but soluble in ether, chloroform, benzene, gasoline and hot alcohol. They have a lower specific gravity than water, and consequently will float on the surface of water when mixed with it.

Chemical Behavior.—

1. *Acrolein Test.*—When a fat is heated to about 300° C., the peculiar odor of "burnt grease" is given off; this is the odor of acrolein, or acryl aldehyde, which is formed from the glycerol part of the fat. The formation of acrolein in-

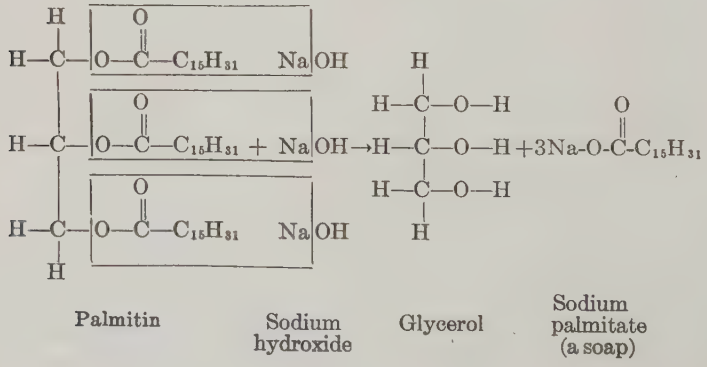
volves the removal of two molecules of water from glycerol, as indicated in the equation below.



This reaction is favored by the presence of a drying agent like sulfuric acid. Hence, a *standard test for fats* is to heat the fatty material with acid potassium sulfate and note the odor of acrolein that is very characteristic.

2. *Oxidation.*—When oxidized completely, fats yield carbon dioxide and water. This reaction takes place readily in the human body, and is attended by the liberation of considerable heat. One gram of fat, when burned either in the body or in the laboratory, yields approximately 9 Calories of heat.

3. *Hydrolysis.*—When fats are boiled with acids or alkalies, or treated with superheated steam, they are split into fatty acids and glycerol. This process is a hydrolysis. If an alkali is used, it reacts with the fatty acids as soon as they are set



free and forms alkali salts of the fatty acids, called soaps. This reaction, which is shown on page 248, is, therefore, called a saponification. Fats may also be hydrolyzed by treating them with certain digestive enzymes; this reaction is the process by which fats are digested in the alimentary tract of animals.

Emulsification.—Oils are insoluble in water. If an oil and water are shaken together, they will mix temporarily, but will separate into two layers very soon after the shaking has ceased. If we add a little soap to the oil and water, and shake the mixture, the latter will become milky, and the oil and water will not separate into two layers. Such a mixture is known as an *emulsion.* In shaking oil, water, and soap together, the oil is thrown into very fine particles which become coated with a thin film of soap. This film of soap keeps the particles of oil from coalescing, and as these particles are very small, they do not settle, being held in suspension by the movement of the water molecules. Other substances, e.g., proteins or gum acacia, may be used to produce emulsions. Milk is an example of an emulsion; the fat particles of milk are emulsified by films of protein.

Emulsification is a very important process. Only emulsified fats are digested to any extent in the stomach; and in the intestine the emulsification of fats by alkaline digestive juices aids greatly in their digestion. The formation of emulsions is also the mechanism by which soaps remove grease and dirt from clothing and from the skin.

Soaps.—Commercial soaps are salts of the higher fatty acids. They are made by boiling fats with sodium or potassium hydroxide. The reaction is as shown above under Hydrolysis. The sodium salts of the fatty acids are hard soaps, and the potassium salts are soft soaps. Sodium stearate or sodium palmitate are examples of hard soaps, and potassium stearate or potassium palmitate are soft soaps.

Commercially soaps are made by boiling fats, which are unfit for food, with sodium or potassium hydroxide. An economical practice among farmers is to utilize "waste" fats by making soaps from them. This is done by boiling the

crude fat with lye, or with a potash solution made by leaching wood ashes with water.

Soaps remove dirt from the skin, or from fabrics, by emulsifying oil or fat particles containing dirt. When the latter are rubbed with water, they are removed and the dirt is carried along with them. Soaps also form colloidal solutions, whose particles have the power of adsorbing dirt and removing the latter in this manner.

Some Important Fats

Butter

Butter is a mixture of several fats. It consists of about 60 per cent palmitin, 30 per cent olein, a little stearin, and 7 per cent of the glyceryl esters of the volatile fatty acids, which are butyric, caproic, caprylic, and capric acids.

Lard

Lard, the fat obtained from swine, is an example of the naturally occurring fats of the animal body. It consists principally of a mixture of palmitin, stearin, and a small amount of olein.

Tallow

Tallow is the fat extracted from sheep and cattle. It is a mixture chiefly of palmitin, stearin, and olein.

Oleomargarine

Oleomargarine consists of animal fats mixed with fats of vegetable origin. When properly prepared, it is a wholesome food and is subject only to the objection that it has a lower vitamin content than the pure butter which it supplants commercially. Upon the recommendation of nutrition authorities there has been a widespread adoption of the practice of fortifying oleomargarine by adding 9,000 International units of vitamin A per pound. Animal experimentation has shown that properly fortified oleomargarine has as high a nutritive value as butter.

Olive Oil

Fats that are liquids at ordinary temperatures are called oils. Olive oil is an example of this class of substances. Olive oil consists principally of olein.

Functions of Fats.—

1. *Energy Value.*—Fats have a high fuel value. When oxidized in the body, they yield approximately 9 Calories of heat per gram, which is the highest energy value of all food substances.

2. *Reserve Food Supply.*—Fats are stored in the body and are, therefore, an important reserve food supply.

3. *Heat Insulation.*—The fats are poor conductors of heat, hence the layers of fat under the skin enable the body to retain better the heat produced by the combustion of foods. This is observed by the reaction of people to extremes of temperature. Thin people suffer more from the cold temperatures of winter than do fat people, and fat people complain most of the hot weather of summer.

4. *Protection Against Mechanical Injury.*—Being deposited around the internal organs and under the skin, the fats fill out the body structures and protect the body against mechanical injury.

Questions for Study

1. Discuss fully the occurrence of fats.
2. What are fats?
3. Name several fatty acids that enter into the composition of fats. Name the fats that are formed from each.
4. Mention several properties of the fats.
5. What is a chemical test for fats?
6. What products are formed when fats are oxidized completely?
7. What is the Calorie value of fats?
8. What is saponification?
9. Explain how an emulsion is formed.
10. What are soaps? Explain how soaps remove dirt.
11. What are the constituents of butter?
12. Chemically, what is lard? Tallow?
13. What is oleomargarine? Is it a satisfactory food?
14. What are the functions of fats?

UNIT XII

CATALYSIS, ENZYMES AND DIGESTION

CHAPTER XXVII

CATALYSIS AND ENZYMES

Catalysis

Definition and General Discussion.—The speed of chemical reactions can often be changed by introducing a third substance. We have previously seen an example of this in the preparation of oxygen from potassium chlorate, where manganese dioxide was used to make the reaction take place more readily. The manganese dioxide apparently took no part in the reaction, except to stimulate the liberation of oxygen from potassium chlorate, and was unchanged at the end of the experiment. Substances like manganese dioxide are called "catalyzers," or "catalysts," and the action of the latter is called catalysis. A catalyst, then, is a substance which changes the speed of a chemical reaction. A positive catalyst makes a chemical reaction take place faster; a negative catalyst makes a reaction go slower. The catalysts with which we deal in this course are positive catalysts, or those which increase the speed of chemical reactions.

Enzymes

Definition and General Description.—The living cells of plants and animals produce a very important class of catalysts called enzymes. *Enzymes are organic catalysts. All enzymes that have been isolated thus far are proteins.* Their activities occur chiefly in living matter, though they do not necessarily have to be in living cells to carry out their work.

Enzymes have great power to make chemical reactions take place more rapidly. For example, the enzyme, rennin, has been shown to have remarkable ability to promote the coagulation of the casein of milk. One part of rennin will

coagulate 72,300,000 parts of fresh raw skimmed milk in 10 minutes under favorable conditions of temperature and hydrogen ion concentration.

Other examples of enzymes are zymase in yeast which acts upon certain sugars, forming alcohol and carbon dioxide; ptyalin in saliva, which aids in the digestion of starch, dextrin and glycogen; and pepsin in gastric juice, which aids in the digestion of proteins.

It is important to understand that enzymes accelerate but do not start chemical reactions. Their function is to make reactions take place faster and not to initiate them. The enzyme-catalyzed reactions that occur in living matter could take place if enzymes were not present, but these reactions would go along so slowly without enzymes that the remarkable properties of living substances would not be exhibited.

Properties of Enzymes.—The more important properties of enzymes are as follows:

1. *Enzymes are specific in their action;* that is, an enzyme will stimulate only one chemical reaction. Pepsin digests proteins and it will not attack carbohydrates, fats, or any other substances. Rennin coagulates the casein of milk and it will not attack any other substance; and zymase will act only upon sugars.

2. *Enzymes require favorable temperatures for their activity.* The enzymes of the human body work best at 37° C. (body temperature). The most favorable temperature for the action of an enzyme is known as its optimum temperature. When heated to 60 to 100° C., most enzymes are inactivated, and some are permanently destroyed. Temperatures as low as the freezing point of water retard the action of enzymes but do not destroy them; if they are placed in a favorable temperature again, they will continue their activity.

3. *Enzymes are active in a limited range of hydrogen-ion concentration.* Some enzymes work best in a medium that is around the neutral point; some require a dilute acid reaction; and others need a slightly alkaline medium for their activity. For example, urease is an enzyme which accelerates the conversion of urea into ammonium carbonate. Urease

has varying degrees of activity within a pH range of 4.0 to 8.8 with optimum activity at pH 6.8 to 7.2; it is inactive below pH 4.0 or above pH 8.8. Pepsin is active in a pH range of approximately 1.0 to 5.0 with optimum activity at pH 1.5 to 2.0. Trypsin is effective at a pH of approximately 7.0 to 10.0, the optimum activity of this enzyme being at a pH of 8.0 to 9.0. Thus, the range of pH in which an enzyme will manifest activity is limited and that in which optimum activity is exhibited is rather narrow.

Substrate.—The substance upon which an enzyme acts is called its substrate. For example, proteins are the substrate of pepsin; casein is the substrate of rennin; and starch is the substrate of ptyalin.

Nomenclature.—The general rule in naming enzymes is to name them after their substrate, changing the suffix of the substrate to "*ase.*" The enzyme which digests lactose is called lact*ase;* the one digesting maltose is called malt*ase;* and the one which digests sucrose is called sucr*ase.* This rule, however, has many exceptions. Some enzymes, like pepsin, trypsin, rennin and ptyalin, have special names which were given to them before a systematic method of naming was established.

Importance.—The great importance of enzymes is that they take a prominent part in the chemical reactions that occur in animals and plants. Such processes as the digestion of foods, respiration, oxidations in the tissues and metabolism in general, are accomplished almost wholly through the activity of enzymes.

Questions for Study

1. What is a catalyst?
2. What are enzymes?
3. Give three properties of enzymes.
4. What is a substrate?
5. What is the general rule for naming enzymes?
6. Why are enzymes so important?
7. Do enzymes start chemical reactions? Explain.

CHAPTER XXVIII

DIGESTION

Necessity for Digestion—Definition.—Most foods must be digested in order that they may be absorbed from the alimentary tract into the blood stream, and thus be made available to the tissues of the body. The food substances requiring digestion are proteins, carbohydrates (except monosaccharides), and fats. These substances exist in the form of very large molecules and, as a general rule, they are not very soluble. Before they can be absorbed from the alimentary canal, many of them must be made more soluble, and their molecules in most cases must be broken down into smaller molecules. The membranes of the intestinal walls do not permit molecules as large as those of proteins, complex carbohydrates, and fats to pass through them. In the process of digestion the complex molecules of food substances are split into simpler molecules. These simpler molecules are much more soluble and will diffuse more rapidly through the walls of the intestine. Digestion may, therefore, be defined as *the chemical processes by which the molecules of proteins, carbohydrates, and fats are broken down into molecules that are more soluble, and are small enough to pass readily through the intestinal walls into the blood and lymph.*

There are certain foods that do not require digestion. These are the inorganic salts, water, vitamins, and simple sugars, or monosaccharides. The molecules of these substances are relatively small and will diffuse readily through the walls of the intestine into the blood stream; hence digestion is unnecessary for substances of this nature.

Digestion is essentially a hydrolytic process. The agents which bring about the hydrolytic reactions are enzymes. When carbohydrates are digested, they are hydrolyzed to monosaccharides through the catalytic influence of enzymes. When fats are digested, their molecules are split by the hydro-

lytic action of certain enzymes, and fatty acids and glycerol are produced. The digestion of proteins is the hydrolytic degradation of protein molecules by enzymes into a series of substances with smaller molecules, called proteoses, peptones, peptides, and amino acids. In each instance the end products of digestion are substances consisting of small molecules, which are quite soluble and will readily pass through the intestinal walls. This process is represented graphically by Fig. 31.

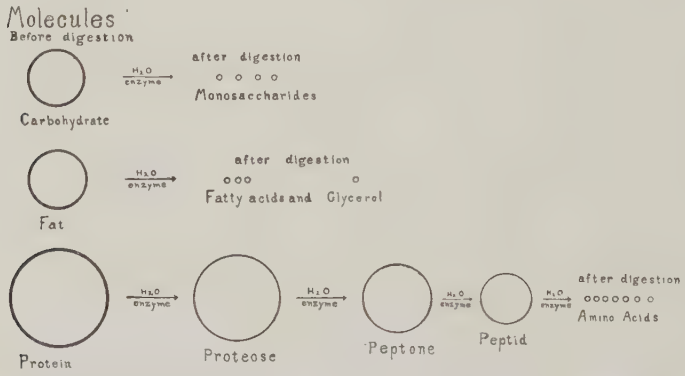


Fig. 31.—Scheme representing change in size of molecules during digestion.

The digestive fluids in the human body are the *saliva,* which is secreted into the mouth by the submaxillary, sublingual, and parotid glands; the *gastric juice,* which is secreted into the stomach by glands in the walls of the latter; the *pancreatic juice,* the external secretion of the pancreas, which is poured into the small intestine at the lower end of the duodenum; and the *intestinal juice,* or *succus entericus,* secreted by Brunner's and Lieberkühn's glands, which are situated in the walls of the small intestine. *Bile* is also considered a digestive fluid since it influences the digestive process in several important respects. Bile passes by way of the common bile duct into the duodenum through an orifice common to the principal duct from the pancreas.

The secretion of saliva and gastric juice is induced by the sight and thought of food, and by the presence of food in the

mouth and the stomach; pancreatic juice is brought forth principally by the presence of food in the duodenum; and intestinal juice is produced probably by a similar mechanism.

Salivary Digestion

The saliva is a fluid consisting of over 99 per cent water; a protein, called mucin, which has a lubricating function; two enzymes, ptyalin and maltase; and small amounts of salts. Its reaction is nearly neutral, ranging from very slight acidity to very slight alkalinity.

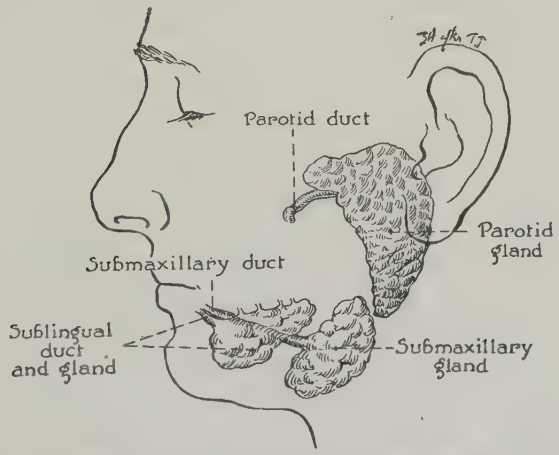


Fig. 32.—The salivary glands. (From McClendon: Pettibone's *Textbook of Physiological Chemistry*, The C. V. Mosby Company.)

When food is taken into the mouth it is first broken up and mixed with saliva by chewing. The saliva has the important functions of moistening the food so it may be readily swallowed, and of digesting cooked starch, dextrins and glycogen. *Starch is digested by ptyalin through successive stages of dextrins to maltose, a process which may be represented as follows:*

Starch → Erythrodextrin → Achroodextrin → Maltose.

Starch digestion by ptyalin action will not take place unless the walls of the starch grains are ruptured by grinding or cooking. This is one of the reasons for cooking food. Ptyalin

will digest starch in a medium that is very slightly acid, or very slightly alkaline. The most favorable range of pH is 6.6 to 7.2. Its action is stopped by increased acidity; at a pH below 4.0 ptyalin action ceases. Salivary digestion, therefore, takes place favorably in the mouth, where the reaction is usually slightly acid, or sometimes slightly alkaline. After the food has been swallowed, it continues in the stomach until the gastric glands secrete enough hydrochloric acid to stop the action of ptyalin. A small amount of maltase, an enzyme which splits maltose into glucose, is present in saliva, but maltase action is very slight in salivary digestion and occurs chiefly in the small intestine.

Gastric Digestion

The gastric juice of mammals contains the enzymes pepsin, lipase and rennin, also hydrochloric acid, mucin and some inorganic salts. In the normal human subject, the acidity of gastric juice increases to a peak in one-half to one hour after ingestion of food, then diminishes slowly to a low value at the end of 2 to 3 hours. At the height of digestion, the pH of normal gastric juice ranges from 1.3 to 2.5.

Pepsin is a proteolytic enzyme. It acts upon proteins breaking them down to proteoses, peptones and peptides. The optimum pH for pepsin activity is 1.5 to 2.0.

The pepsin of gastric juice arises from an enzymic precursor, or zymogen, which is called pepsinogen. Pepsinogen is secreted by the chief cells and hydrochloric acid by the parietal cells of the gastric mucosa. After pepsinogen and hydrochloric acid have passed into the lumen of the stomach and the gastric juice has become more acid than a pH of 6, the pepsinogen is converted into pepsin. Once the process is started, it takes place more rapidly due to the presence of pepsin itself; that is, the reaction is autocatalytic, the presence of pepsin facilitating the formation of more pepsin from pepsinogen.

When pepsinogen is converted into pepsin, another compound, an inhibitor of pepsin, is formed. This compound combines with pepsin at a pH between 5.4 and 8.0, and

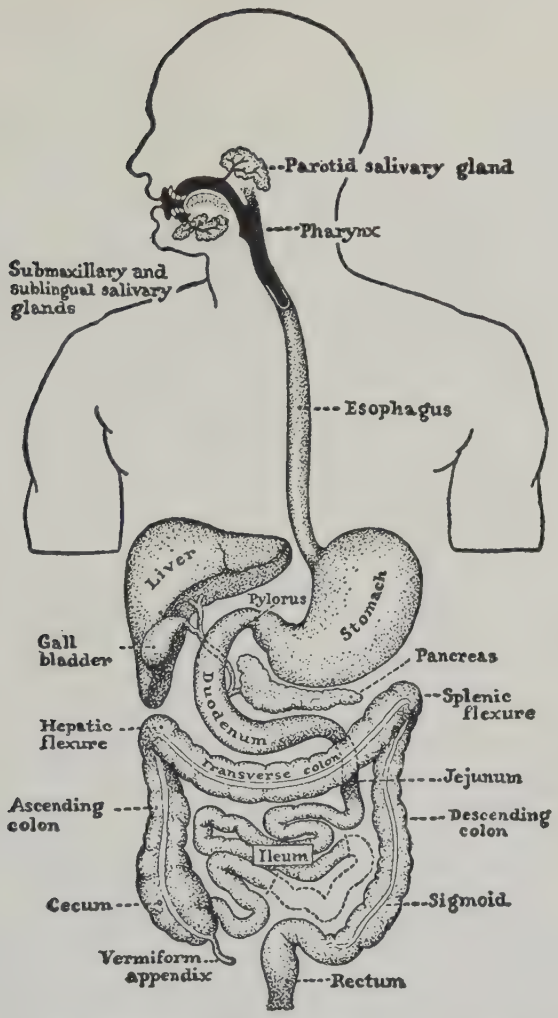


Fig. 33.—The relationships of the different parts of the digestive system. Only a small part of the small intestine is shown. (From Turner: Personal and Community Health, The C. V. Mosby Co.)

prevents its action. Above a pH of 8 pepsin is destroyed by the alkali present. Pepsinogen is not inactivated by moderate amounts of alkali.

Rennin is an enzyme which coagulates, or clots, milk. Rennin action is a hydrolysis or splitting of the casein of

milk, forming a compound called paracasein, which, in the presence of calcium ions, becomes calcium paracaseinate, an insoluble curdy substance. Rennin serves a double function: it produces paracasein, whose molecule is smaller than casein; and, as calcium paracaseinate is insoluble, the formation of the latter slows down the passage of milk through the alimentary tract, thereby permitting a more prolonged action upon this substance by other digestive enzymes. The optimum pH for rennin action is 5.4.

Rennin occurs in the gastric juice of young mammals. The evidence indicates that there is very little, or perhaps not any rennin in the gastric juice of adult mammals. Rennin action, however, does take place in the alimentary tract of the mammalian adult, but this is apparently an effect of the protolytic enzymes, pepsin, trypsin and chymotrypsin. The latter enzymes in pure crystalline form have been shown to have an action upon casein similar to that of rennin.

In gastric juice there is an enzyme, called lipase, which splits emulsified fats into fatty acids and glycerol. Only emulsified fats can be attacked by lipase, and the optimum pH for this enzyme is 5.0, hence there is very little digestion of fats in the stomach of the adult.

As the average pH of infant's gastric juice is 5.5, the digestive action of lipase, also rennin, is greater, and of much more importance, in the infant than in the adult.

After foods have entered the stomach considerable digestion of starch takes place, as noted above. There is no other carbohydrate digestion in the stomach than that performed by ptyalin upon cooked starch, dextrins and glycogen, except possibly a slight hydrolysis of sucrose, maltose, or lactose, by the hydrochloric acid of the gastric juice.

Gastric juice contains a variable amount of the glycoprotein, mucin. This compound is secreted by the goblet cells of the mucous membranes of the alimentary tract. *The function of mucin is to serve as a lubricant to promote the passage of food along the alimentary tract, to protect the membranes against trauma by coarse food particles, and in the stomach to act as a buffer against acidity.* It is well adapted to the latter function, as it is a protein which will

combine with acid, and it is viscous and sticky, a property that makes it cling to the walls of the stomach.

The combined action of the gastric enzymes in the presence of hydrochloric acid reduces the food to a thin liquid, called chyme. As gastric digestion is completed, the acid chyme is gradually passed into the small intestine by successive, wavelike contractions of the stomach (peristalsis) which pass from the region of the fundus to that of the pylorus.

The Clinical Testing of Gastric Function

In cases of chemical imbalance in the gastric juice or failure in gastric secretion, information of value may be obtained by a gastric analysis. In such a procedure, the flow of gastric juice is stimulated by giving the patient a test meal of bread, alcohol, or other food, or by the injection of histamine, and gastric juice is collected at intervals through a stomach tube. The material obtained is examined microscopically and chemically in the clinical laboratory.

The finding of blood in the gastric contents shows the presence of a bleeding lesion in the upper alimentary tract. Marked excesses of bile suggest obstruction below the outlet of the common bile duct. Large numbers of yeast cells indicate that active fermentation has occurred in the stomach, a condition associated with a low secretion of hydrochloric acid. Remnants of food from a previous meal show poor emptying capacity of the stomach. In the chemical examination the factor of principal interest is the amount of hydrochloric acid secreted. Complete absence of free HCl after an effective stimulus, such as histamine, indicates severe pathology in the secretory cells of the gastric mucosa. A low secretion of HCl may indicate a poor functional capacity or a gastritis. A high HCl concentration in the gastric juice is often associated with a gastric or duodenal ulcer or pyloric spasm.

Digestion in the Intestinal Tract

Protein Digestion.—In the intestine the digestion of proteins is continued through the activity of the enzymes trypsin, chymotrypsin, carboxypeptidase, aminopeptidase, and dipeptidase.

Trypsin arises from a precursor, trypsinogen, which is secreted by the pancreas. Trypsinogen is converted into trypsin in a medium that has a pH of 6.0 to 9.0. This reaction is autocatalytic; that is, the presence of trypsin itself accelerates the formation of more trypsin from trypsinogen. What is also very important in this connection is that the intestinal glands secrete *an enzyme, called enterokinase, which very actively promotes the formation of trypsin from trypsinogen* as soon as the latter appears in the intestinal tract. *Trypsin catalyzes the hydrolysis of proteins to proteoses, peptones and peptides. It also has a weak rennin-like action on casein.*

Chymotrypsin arises as a zymogen, or precursor, called chymotrypsinogen, which is secreted by the pancrease. In the intestinal tract, chymotrypsinogen is converted into the active proteolytic enzyme, chymotrypsin, through the action of trypsin in a medium with a pH of 6.0 to 10.0 *Chymotrypsin splits proteins into proteoses, peptones and peptides. It also has a rennin-like action upon casein.* Its rennin action is much greater than that of trypsin.

Trypsin and chymotrypsin have proteolytic activity in a medium with a pH ranging from 7.0 to 11.0. Their optimum activity is at a pH of 8.0 to 9.0. There is a trypsin inhibitor which combines with trypsin, also chymotrypsin to a lesser extent, and interferes with the action of these enzymes at a pH of 3.0 to 7.0. At a pH above 7.0, trypsin inhibitor does not function.

As stated above, trypsin and chymotrypsin split proteins down to the peptide stage. We also noted under gastric digestion that proteins are hydrolyzed by pepsin to proteoses, peptones and peptides. To complete the digestion of proteins, it is necessary that the peptides be split into amino acids. This is accomplished by the action of several enzymes.

One of the peptidolytic enzymes is carboxypeptidase, which is secreted by the pancreas. *Carboxypeptidase attacks a peptide with a free carboxyl group upon an amino acid at one end of the peptide chain. The action of this enzyme is to*

split off from the molecule the amino acid with the free carboxyl group and then react in a similar manner with the next amino acid in the chain and so on until the peptide chain has been hydrolyzed into amino acids.

Another peptidolytic enzyme is aminopeptidase which is present in the secretion of the glands of the intestinal mucosa. *Aminopeptidase acts upon the end of a peptide chain which has an amino acid containing a free amino group, splitting off the latter amino acid. After having split off one amino acid with a free amino group, the action is continued in a stepwise manner until the peptide has been hydrolyzed into amino acids.* Another peptide-splitting enzyme of the intestinal juice is dipeptidase. *As the name indicates, dipeptidase splits peptides consisting of two amino acids.* This enzyme serves a useful function in splitting dipeptides that either have escaped, or are resistant to, the action of other peptidolytic enzymes.

Carbohydrate Digestion.—In the fluid mixture that is delivered into the duodenum by gastric peristalsis there may be considerable undigested starch, also dextrin, glycogen, maltose, sucrose and lactose. The digestion of these carbohydrates is completed in the intestinal tract through the activity of certain enzymes which will now be discussed.

The pancreas secretes a starch-splitting enzyme called amylopsin. *The amylopsin of pancreatic juice hydrolyzes starch, glycogen and dextrins to maltose.* In the pancreatic juice and also in the intestinal juice, there is present *the enzyme, maltase, which splits maltose into glucose.* In addition to maltase, the succus entericus contains the enzymes, sucrase and lactase. *Sucrase hydrolyzes sucrose forming glucose and fructose. Lactase splits lactose into glucose and galactose.* Thus the undigested carbohydrates that appear in the upper intestinal tract are rapidly converted into monosaccharides by the action of certain enzymes in pancreatic and intestinal juice.

Fat Digestion.—In mammals most fat digestion occurs in the small intestine. The digestion of fats is brought about by

the action of the enzyme, steapsin, of the pancreatic juice upon emulsified fats. *Steapsin splits fats into fatty acids and glycerol.* Since steapsin exists in aqueous solution and fats are not water soluble, the problem of obtaining steapsin action is a matter of creating conditions which will bring about contact between the molecules of the enzyme and its substrate. This is accomplished by emulsification of the fat, bile being the emulsifying agent. Bile contains alkaline salts of the bile acids which form thin films around minute colloidal particles of fat and thus produce an emulsion, or colloidal solution, of fat. These emulsified colloidal particles of fat are readily attacked by steapsin. Thus the emulsification of fats by bile serves the very important function of enabling steapsin to attack fats and split them into fatty acids and glycerol.

Digestion of Nucleoproteins

Nucleoproteins are constituents of the cell nuclei of plant and animal tissues, hence they make up a small part of the substances consumed as foods. The nucleoprotein molecule, which consists of a protein combined with nucleic acid, is large and requires digestion to make its parts available as nutrients. The digestive fluids secreted into the upper intestinal tract contain certain enzymes which act upon nucleoproteins and break them down into their constituent units. The molecules of the latter are soluble and small enough to be absorbed from the alimentary tract.

The first step in the digestion of nucleoproteins is a splitting of the molecule into a protein and nucleic acid by the action of pepsin in the stomach and trypsin in the intestine. The protein is digested as described above. Nucleic acids are split into smaller units, called mononucleotides, by nucleases, enzymes found in pancreatic and intestinal juices. The mononucleotide molecule is too large to permit absorption and requires further fragmentation. A mononucleotide consists of a purine or pyrimidine base combined with a pentose which in turn is attached to a phosphate group.

The phosphate group of the mononucleotide is split off by an enzyme, called phosphatase, which is found in pancreatic juice, succus entericus and bile. The remaining part of the mononucleotide molecule is called a nucleoside. It is split by nucleosidase into a purine or pyrimidine base and a pentose. The molecules of the latter substances are small and can be absorbed.

Supplementary Action of Enzymes in the Digestive Tract

In the foregoing discussion, it is interesting to note how the enzymes supplement the work of each other. Pepsin starts the digestion of proteins in the stomach and produces proteoses, peptones and peptides. In the intestine, trypsin and chymotrypsin continue the digestion of proteins and yield proteoses, peptones and peptides. Further digestion of the products formed from proteins by the action of pepsin, trypsin and chymotrypsin is accomplished by carboxypeptidase, aminopeptidase and dipeptidase, which promote the hydrolysis of peptides to amino acids. Starch is attacked by ptyalin in the mouth and in the stomach for a time, but whatever starch escapes ptyalin action is digested in the intestine by amylopsin of the pancreatic juice. The maltose that is produced by the action of ptyalin and amylopsin is digested further in the intestine by maltase which splits this disaccharide into glucose. Emulsified fats are digested to a slight extent in the stomach, but fat digestion is carried on effectively and completed in the intestine by steapsin in the presence of bile. The protein part of the large molecules of nucleoproteins is split off by pepsin and trypsin, and the nucleic acid is digested into its constituent units by nuclease, phosphatase and nucleosidase. Thus, each enzyme plays an effective part in the whole process of digestion and the final result is the production of monosaccharides, amino acids, fatty acids, glycerol, phosphates, purines and pyrimidines, substances whose molecules are relatively small.

The student will be aided greatly in the study of digestion by Table XI, which summarizes the process.

TABLE XI

SUMMARY OF DIGESTION

SECRETION	MOST FAVORABLE REACTION	ENZYME	SUBSTRATE	END PRODUCTS
Saliva	Slightly alkaline to slightly acid, pH 6.6 to 7.2	Ptyalin	Cooked starch, dextrins and glycogen	Maltose
		Maltase	Maltose	Glucose
Gastric juice	Acid, pH, 1.5 to 2.0*	Pepsin	Proteins	Proteoses, peptones, peptides
		Rennin	Casein	Paracasein
		Lipase	Emulsified fats	Fatty acids and glycerol
Pancreatic juice	Alkaline, pH 7.0 to 9.0	Trypsin and chymotrypsin	Proteins	Proteoses, peptones, peptides
		Amylopsin	Starch, dextrins and glycogen	Maltose
		Steapsin	Fats	Fatty acids and glycerol
		Maltase	Maltose	Glucose
		Carboxypeptidase	Peptides	Amino acids
Intestinal juice	Alkaline, pH 7.0-9.0	Aminopeptidase	Peptides	Amino acids
		Dipeptidase	Dipeptides	Amino acids
		Maltase	Maltose	Glucose
		Lactase	Lactose	Glucose and galactose
		Sucrase	Sucrose	Glucose and fructose
		Nuclease	Nucleic acid	Mononucleotides
		Phosphatase	Mononucleotides	Nucleosides, phosphates
		Nucleosidase	Nucleosides	Pentoses, purines and pyrimidines

*pH of 1.5 to 2.0 is optimum for pepsin; the pH optimum for rennin is 5.4 and for gastric lipase is 5.0.

Questions for Study

1. Why is digestion necessary?
2. What is digestion? What are the agents chiefly responsible for digestion?
3. What foods do not require digestion? Why?
4. Name the digestive fluids.
5. How is the secretion of digestive fluids brought about?
6. Describe the digestion of carbohydrates in the mouth; the stomach; the intestine.
7. Describe the digestion of proteins in the stomach; the intestine.
8. Describe the digestion of fats in the stomach; the intestine.
9. What is the most favorable reaction (acidity or alkalinity) for salivary digestion? For gastric digestion? For intestinal digestion?
10. How does bile aid in digestion?
11. Name all of the enzymes that digest the following substances in the alimentary tract: carbohydrates, proteins, fats.
12. Name the end products of digestion by each of the enzymes of the alimentary tract.

UNIT XIII

METABOLISM

CHAPTER XXIX

METABOLISM OF CARBOHYDRATES, FATS, PROTEINS AND INORGANIC SALTS

Definition.—Metabolism is a term used to indicate the chemical changes that take place in the living tissues of plants and animals. In man it includes all of the *chemical changes taking place in the body after food is absorbed from the alimentary tract.* It does not include digestion. It is the story of the construction and repair of tissues; the storage of food substances in the body; the nutrition of all the cells; the conversion of the chemical energy of absorbed foodstuffs into mechanical work, which is manifested in bodily movement; and the elimination of waste products from the body. Metabolism includes two general processes: (1) constructive metabolism, or *anabolism,* the building up of body tissues and the storage of foods in the body; (2) destructive metabolism, or *catabolism,* the breaking down of body tissues and of food substances in the body.

Metabolism of Carbohydrates

Anabolism.—As we have previously seen, carbohydrates are digested in the alimentary tract, forming the monosaccharides, glucose, fructose, and galactose. The monosaccharides pass through the intestinal walls into the blood stream. *The blood carries the glucose to all parts of the body, where it either is oxidized to give heat and energy, or is stored in the tissues in the form of the polysaccharide, glycogen.* For a time after the ingestion of a meal, fructose and galactose may be present in the blood stream, but these monosaccharides are soon converted into glucose or glycogen. Glucose is present in the blood and tissues at all times. Gly-

cogen exists in the body as a storage form of carbohydrate, being present always when the body is well fed with carbohydrates.

Glucose is the true sugar of the blood. It is fermentable with yeast. The term "blood sugar" includes glucose and a small amount of nonfermentable substances that are not sugars. In a chemical analysis of the blood for its sugar content a small amount of nonsugar substances enters into the blood sugar value obtained, because the blood sugar methods of analysis are not entirely specific for glucose. The best blood sugar methods give values that include less than 10 per cent of nonsugar substances.

The amount of glucose in the blood of normal human subjects ranges from 65 to 100 milligrams per 100 cubic centimeters of blood. From one-half to one hour after a carbohydrate meal has been ingested, the blood sugar rises to about 120 to 160 milligrams per 100 c.c.; but as glucose is rapidly converted to glycogen, this blood sugar concentration returns to the normal level of 65 to 100 milligrams per 100 c.c. within two or three hours. The blood sugar thus tends to stay at a constant level in health. When an excess of glucose appears in the blood following carbohydrate ingestion, it is promptly stored in the liver and the muscles as glycogen, this process being promoted by insulin, a secretion of the Islands of Langerhans of the pancreas. When the glucose of the blood is used for metabolic processes, it is renewed from the glycogen stored in the liver, and glycogen in this manner serves as an immediate source of glucose during the fasting hours.

When the body is in a well-nourished condition, glycogen is always present in the muscles and the liver. The glycogen content of the body is about 300 to 400 grams, or less than one pound. The storage of glycogen is small as compared with the deposition of fat in the body.

Catabolism.—The liver has the capacity to remove sugar from the blood and store it as glycogen following a meal, or to liberate glucose into the blood stream during the time that food is not being absorbed from the alimentary tract. A con-

siderable part of the glucose delivered into the blood stream by the liver is formed from glycogen but the liver also has the capacity to form glucose from sugar-forming amino acids obtainable from proteins. The latter process is especially important when the glycogen content of the liver becomes low as a result of a reduced carbohydrate intake. Thus the liver provides a mechanism by which glucose may always be supplied to the body. This is a very important mechanism, as glucose is being oxidized in the body at all times to provide heat and energy for its vital processes.

The breakdown of glycogen into glucose in the liver is accomplished as follows. The glucose unit at the end of the chain in a glycogen molecule is combined with a phosphate group through the activity of an enzyme called phosphorylase. The glucose-phosphate unit is next split off from the glycogen molecule. The phosphate group under the direction of an enzyme called phosphoglucomutase wanders from carbon atom number 1 to carbon atom number 6 of the glucose molecule. The glucose-6-phosphate is then split into glucose and phosphate by the action of liver phosphatase. In this manner, glucose is released from glycogen in the liver and delivered to the blood to be carried to all parts of the body. This process is called glycogenolysis.

The formation of glucose from glycogen in the liver is accelerated by adrenalin, a hormone secreted by the adrenal glands. This stimulation of glycogenolysis by adrenalin is important in that it provides a mechanism by which blood sugar is quickly mobilized in times of stress when there is a special need for more blood glucose. One effect of adrenalin upon carbohydrate metabolism then is to raise the blood sugar by increasing the breakdown of glycogen to glucose in the liver.

Glucose is carried to the tissues by the blood. In the muscle tissues glucose is converted to glycogen. When glycogen is used by the muscles, hexose phosphates are formed as described above in discussing the breakdown of glycogen to glucose in the liver. The hexose phosphates are split in the

middle of the molecule into three-carbon fragments that give rise to the formation of lactic acid. A part of the lactic acid is oxidized to carbon dioxide and water, thereby liberating considerable energy for the recovery of muscle following activity or for other vital processes; and the remainder of the lactic acid is transported by the blood to the liver where it is reconverted to glycogen.

All of the above stages in the metabolic breakdown of carbohydrate are under the directing influence of enzymes. The purpose of the phosphorylation of sugars is to provide a group, or groups, attached to the sugar molecules with which enzymes can combine and thus facilitate their action. Insulin apparently stimulates some stage in the above reactions by which the oxidation of glucose is accomplished.

The mechanism of carbohydrate catabolism is more complicated than is here indicated, but further discussion need not be presented in a course of this kind. It only remains to be emphasized that carbohydrates are the chief source of the energy that is used for the mechanical movements of the body. This is the principal reason why a balanced diet contains about 50 to 60 per cent of the total calories in the form of carbohydrates.

Abnormal Metabolism of Carbohydrates

Diabetes Mellitus.—As has already been stated, insulin is necessary for the storage of glucose in the form of glycogen and also for the oxidation of glucose. When insulin is not secreted in sufficient quantities, the condition known as *diabetes mellitus* exists. This disease is characterized by an inability to utilize glucose, giving a high blood sugar (150 to 1,500 mg. per 100 c.c. of blood under fasting conditions); and, as a consequence of the failure to burn sugar, there is an increased production of the so-called "acetone bodies," namely, acetoacetic acid, β-hydroxy-butyric acid, and acetone. As a result of increased sugar and acetone bodies in the blood, sugar and acetone bodies will pass through the kidneys and appear in the urine in greatly

increased quantities. The blood sugar level at which sugar begins to appear in the urine is known as the *sugar threshold.* This varies widely in different individuals. In about 50 per cent of diabetics sugar begins to appear in the urine when the blood sugar is from 150 to 190 mg. per 100 c.c. of blood. Some individuals, however, excrete sugar in the urine when the blood sugar is at the normal level, a condition known as *renal diabetes.* Others do not begin to excrete sugar in the urine until the blood sugar is quite high (200 to 300 mg. per 100 c.c. of blood).

The Nutritional Requirement of Carbohydrate

The tissues of the body need glucose at all times. Either glucose, or substances that yield glucose by digestion or metabolism, must be in the diet. If the blood sugar of an animal is decreased by an experimental procedure, the animal becomes sick, and if the concentration of sugar in the blood is lowered sufficiently, the animal will die.

Considerable glucose is eaten as such, and thus serves to maintain the stores of glucose in the body. Other assimilable carbohydrates either yield glucose by digestion in the alimentary tract or form glucose by metabolic conversion in the body. The body thus obtains glucose, or glucose precursors, from the food that is ingested.

In case of starvation or deficient food intake, the body has two possible sources of glucose. Either the glycogen of the liver may be broken down to form glucose, or certain amino acids may be converted into glucose by the liver. The conversion of amino acids into glucose by the liver is especially important when the glycogen stores are exhausted. The latter mechanism serves as a safety device to provide the tissues with a constant supply of glucose when alimentary sources of this sugar have failed. It is thus seen that the body has certain mechanisms which operate successfully in case there is an inadequate intake of carbohydrate; however, it is obvious that the diet should contain an abundant amount of carbohydrate to provide directly for the glucose requirements of the body.

Since the body uses carbohydrates for the production of energy, the amount of carbohydrate in the diet is dependent upon the activity of the individual. This amount varies from 400 to 1,000 grams per twenty-four hours.

Metabolism of Fats

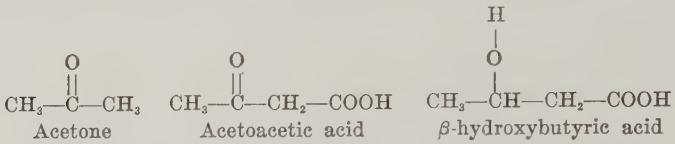
Anabolism.—The fats are digested to fatty acids and glycerol by the action of gastric lipase and the pancreatic enzyme, steapsin. The fatty acids and glycerol diffuse into the intestinal epithelium, and as they pass through the intestinal membranes they recombine to form neutral fats again. These neutral fats enter the central lacteals of the intestinal villi, and pass by way of the abdominal lymphatics into the thoracic duct and finally into the blood stream. The absorption of fats differs from that of carbohydrates and proteins in that the major portion of the absorbed fats pass into the lymphatic system before entering the blood. *The blood carries the absorbed fats to all parts of the body, where they either are stored as fatty tissue or are oxidized to give heat and energy.*

Catabolism.—***Fats are oxidized in the human body to carbon dioxide and water, a chemical reaction which liberates 9 Calories of heat per gram of fat.*** The heat produced by the oxidation of fats is utilized to maintain body warmth, and as energy for the production of body movements. Fats are a less important source of mechanical energy than carbohydrates.

The glycerol part of the fat molecule follows the same pathway of metabolism as carbohydrate, as the glycerol molecule is somewhat similar in structure to one-half molecule of a hexose. In a discussion of fat catabolism one would, therefore, be concerned primarily with the chemical changes undergone by the fatty acids. A complete discussion of the catabolism of fatty acids is not desirable in a course of this kind. However, a consideration of the metabolism of the acetone bodies, substances formed in the oxidation of fatty acids, is of importance for this course and will be given below.

The Metabolism of Acetone Bodies

The acetone bodies are acetone, acetoacetic acid and β-hydroxybutyric acid. Their formulas are given below.



These compounds are formed in the oxidative breakdown of fatty acids. They are of considerable interest.

The acetone bodies are normal products of metabolism. They are formed by the liver and are utilized principally by the muscles. When the acetone bodies are delivered to the muscles by the blood they undergo further metabolic breakdown and are finally oxidized to carbon dioxide and water, thereby yielding considerable energy. In a normal animal receiving a diet properly balanced with respect to carbohydrate and fat the amount of acetone bodies formed by the liver does not exceed the quantity the muscles can oxidize. If, however, the diet contains too little carbohydrate or too much fat, there will be formed more acetone bodies than the muscles (and other tissues) can utilize and the excess of acetone bodies produced is excreted in the urine; also, if the animal has a deficient insulin secretion (diabetes mellitus), the carbohydrates are not metabolized correctly and this will give rise to excess acetone body formation. The factor that prevents the formation of excess acetone bodies by the liver is the amount of carbohydrate utilized. This is because carbohydrate is preferentially utilized in the animal body and anything that interferes with the utilization of adequate amounts of carbohydrate, such as a low carbohydrate diet, starvation, or insulin deficiency, will cause a shift of metabolic processes in the liver to a greater use of fatty acids with a resulting increase in acetone body production. Obviously a high fat diet limits the amount of carbohydrate available to the animal and will also give rise to the production of acetone bodies. Some acetone bodies are formed from the amino

acids, leucine, tyrosine and phenylalanine, but this is a small source compared with the amount obtainable from fatty acid catabolism.

The acetone bodies are also called ketone bodies because a ketone group is present in the molecule of two of them. From this discussion it is clear that the fatty acids are ketone-forming, or ketogenic substances, and that carbohydrates are antiketogenic substances. The balance between the amounts of carbohydrate and fat in the diet is very important. If the ratio of fat to carbohydrate becomes too high, excess acetone bodies are formed. The highest permissible ratio of fat to carbohydrate in the diet that will not result in excess acetone body formation is 1.5 grams of fat to 1 gram of carbohydrate. Thus, if 1 gram of carbohydrate is utilized while not more than 1.5 grams of fat are being metabolized, there is no danger of excess acetone body formation.

As noted above, the acetone bodies are normal intermediary products in the catabolism of fatty acids. They become harmful, or pathologic, when produced in greater quantities than the muscles can oxidize and the excesses are excreted in the urine. The pathologic effect is due to the fact that two of the acetone bodies are acids and require neutralization by bases. If the acetone bodies are oxidized in the muscles, or other tissues, the basic ions remain in the body; but if these substances are excreted in the urine, they carry the bases along with them and these basic constituents are lost from the body. Excess acetone body formation thus brings about an exhaustion of the bases of the animal's body, a process that leads to an acidosis. This is a serious condition. Previous to the discovery of insulin, acidosis was the cause of death in about two-thirds of all cases of diabetes mellitus. Now diabetic acidosis can be relieved or prevented by the subcutaneous administration of insulin which brings about correct metabolism of carbohydrates and thus prevents excess acetone body formation from fat. From this discussion it is clear that a diet properly balanced with respect to carbohydrate and fat is important in preventing a diabetic acidosis; and the same dietary balance is also essential to prevent acidosis in a normal subject.

The Nutritional Requirement of Fat

Fats are of nutritive importance as sources of energy and as food substances which are readily stored. They are also of value as structural materials, giving form to the body and physical support to certain internal organs.

There are three unsaturated fatty acids, linoleic, linolenic, and arachidonic acids, which are apparently indispensable for correct nutrition. Rats placed upon a diet that is fat-free, but otherwise adequate, develop symptoms of a deficiency disease and do not survive long. Addition of linoleic, linolenic, or arachidonic acid to such a diet will correct this condition or prevent its onset. It appears from experiments of this kind that *linoleic, linolenic, and arachidonic acids are indispensable constituents of the diet.*

The amount of fat in the diet is subject to variations due to activity and to climate, and must be regulated according to the carbohydrate content, since fats will give rise to excess acetone body formation unless adequate amounts of carbohydrates are being utilized. The quantity of fat that is desirable in the diet varies from 100 to 200 grams per twenty-four hours.

Metabolism of Proteins

Anabolism.—Proteins are digested to amino acids by the action of the proteolytic enzymes of the alimentary tract. The amino acids pass readily through the walls of the intestine into the blood stream. During the digestion and absorption of a protein meal the amino acid content of the blood increases, but the blood rapidly distributes these absorbed protein products to all the tissues of the body, and the amino acid concentration of the blood soon returns to the normal fasting level.

Since the body tissues are composed largely of proteins, and there is a constant wear and tear upon these tissues, it is important for the body to be supplied continuously with amino acids from which proteins may be constructed. *The amino acids obtained from the proteins of the diet are, therefore, utilized for the important function of tissue building.*

These substances may be used for the construction of new body tissues, as in the growth of the young, or they may be used for the repair of tissues in both the adult and the young. Amino acids are also used in the formation of enzymes and internal secretions. Proteins are, therefore, absolutely essential for the maintenance of life. If proteins are not present in the diet, amino acids are withdrawn from the less essential parts of the body, and are used to nourish the more vital parts of the body like the heart and the brain. In starvation the muscles and peripheral portions of the body lose protein most rapidly, and the heart and brain are the last to show a decrease in their protein content. A protective, or "sparing," metabolism thus exists in the body, but an individual cannot live long upon a protein-free diet, even though an abundance of carbohydrates and fats is eaten.

Unlike carbohydrates and fats, proteins are not stored in the bodies of adults normally. Practically the only instances of protein storage are in the growing young, in underweight convalescents from wasting diseases, in individuals recovering from starvation, and in individuals undergoing vigorous physical exercise who may to a limited extent store proteins for a short period of time. With these exceptions, the anabolic function of proteins is confined to the renewal of body tissues, in which case storage does not occur.

Proteins are converted to carbohydrates in the human body, especially when there is a deficiency of carbohydrates in the diet, or when the body is unable to burn carbohydrates properly, as in diabetes mellitus. The amount of conversion varies according to the diet up to a maximum of 58 per cent. Hence in calculating the amount of carbohydrate in a diet for a diabetic, 58 per cent of the protein allowed is considered as available carbohydrate.

Catabolism.—*The amino acids absorbed into the body, which are in excess of the requirements for tissue construction, or are not the correct type for tissue building, are oxidized.* When oxidized, the amino acids produce carbon dioxide, water, urea, and ammonium compounds, chiefly. This reaction liberates 4 Calories of heat per gram of protein.

The Nutritional Requirement of Protein

The determination of the amount of proteins that should be in the diet is based upon several considerations. In the first place, there must be a balance between the intake of proteins and the loss of proteins from the body as a result of metabolic activities. Since approximately 16 per cent of protein is nitrogen, and nitrogen can be readily determined chemically, the protein content of a substance is measured by means of a chemical estimation of its nitrogen content. The intake of proteins may, therefore, be measured by a chemical determination of the nitrogen content of the food that is ingested, and the loss of proteins from the body, due to catabolism, may be determined by estimating the nitrogen content of the urine and feces.

Measurement of the nitrogen intake and output of the body is thus a means of studying the adequacy of a diet with respect to its protein content. *When the nitrogen intake of the body is equal to its nitrogen output, the condition is called nitrogen equilibrium. If the nitrogen intake is greater than the nitrogen output, the individual is said to be in positive nitrogen balance.* Such a condition may exist in the growing young, in recovery from a wasting disease or from starvation, and to a very limited extent as a result of vigorous muscular activity. *Negative nitrogen balance exists when the nitrogen intake is less than the nitrogen output.*

A consideration of nitrogen equilibrium only is not a complete criterion for the establishment of a proper protein intake. The degree of protein catabolism, which determines the losses of nitrogen from the body, varies according to the amount of carbohydrate and fat in the diet. When the diet does not contain sufficient carbohydrate, the liver makes glucose from available proteins, a process which increases the losses of nitrogen from the body. The nitrogen losses of the body are high when there is little or no carbohydrate and fat in the diet, and are low when the diet contains an abundant amount of the latter food constituents. It obviously would not be satisfactory to set the protein requirement at the amount which the body loses during starvation, or the

quantity that is metabolized when an individual is on a diet containing proteins only, because the latter situations compel an abnormal protein catabolism to supply the body's need for glucose. Neither would it be desirable to establish the protein requirement as the minimum amount that will maintain nitrogen equilibrium when the diet contains an abundant amount of carbohydrate and fat. Such an amount is too close to the borderline requirement for practical maintenance and does not take into consideration the fact that the proteins ingested vary widely in their capacity to satisfy the nutritional requirements of the human body.

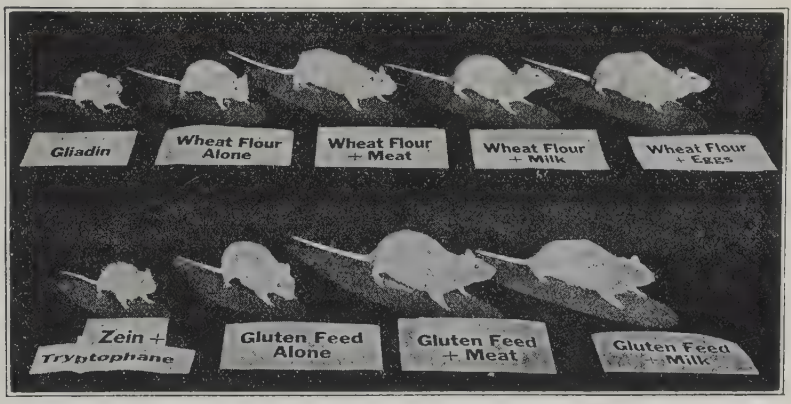


Fig. 34.—Effect of different proteins upon the growth of rats. These rats were all of the same age and fed for the same length of time on diets containing the same proportion of protein. The variation in size is due to differences in the chemical composition of the proteins eaten. Gliadin is deficient in the amino acid, lysine. Zein lacks tryptophane and lysine. (From Mendel: *Nutrition: The Chemistry of Life*, 1923, Yale University Press.)

Some proteins of Nature are qualitatively deficient as constituents of the diet of man, because they do not contain certain amino acids which the human body needs and is unable to synthesize. The protein foods that most readily satisfy the requirements of man are those having an amino acid composition most similar to that of his own body. Proteins of animal origin have the highest nutritional value to man, because they contain a greater amount of the amino acids which the human body cannot synthesize. Based upon a general

interpretation of rat feeding experiments, the nutritional value of the proteins of various foods arranged in order of diminishing superiority are: eggs, milk, meats, whole wheat, potatoes, rolled oats, whole corn, peanuts, and navy beans.

The importance of the qualitative nature of the proteins of the diet has been revealed by investigators who studied the effects of synthetic diets upon the growth and well-being of rats. The early experiments consisted of feeding a diet containing carbohydrate, fat, salt mixture, vitamins, water, and some purified protein. From such experiments Osborne

Fig. 35.—The upper photograph shows the effect of a dietary deficiency of the amino acid, valine. The lower photograph shows the same animal after valine had been administered for twenty-five days. (Rose and Epstein: J. Biol. Chem. 127: 683, 1939. Courtesy of Dr. W. C. Rose and the Journal of Biological Chemistry.)

and Mendel found that rats would grow upon a diet in which the protein constituent was either casein, lactalbumin, egg albumen, glutenin of wheat, glutelin of corn, or globulin of cottonseed. In other experiments these investigators found that when either gelatin, or gliadin of wheat, zein of corn, hordein of barley, or phaseolin of the white kidney bean was used as the sole source of protein, the rats would not grow. Osborne and Mendel found by further experimentation that the proteins which would not bring about main-

tenance and growth of rats were deficient in certain amino acids. Other investigators have confirmed Osborne and Mendel's results and have found further that histidine, methionine, leucine, isoleucine, phenylalanine, valine, threonine and arginine must be present in the proteins of the diet in adequate amounts to obtain growth of rats. Thus, *it is now known that in the proteins of the food there must be present at least 10 amino acids (lysine, tryptophan, histidine, methionine, leucine, isoleucine, phenylalanine, valine, threonine, arginine) to bring about correct nutrition in the rat. These are known as essential or indispensable amino acids.* Experimentation upon human subjects up to the time of this writing has shown that at least 9 of these amino acids are essential in the diet of man. A diet may contain considerable protein, but it will not be adequate nutritionally unless the above-mentioned essential amino acids are present in the protein in sufficient amounts.

Based upon a statistical study of the protein content of the diet of the German people, Voit proposed that the diet should contain about 118 grams of protein per day. Chittenden, on the other hand, from an extensive series of experiments with soldiers and laboratory workers upon various diets, found that a man of average size could be maintained in nitrogen equilibrium upon a protein intake of 44 to 53 grams per day.

Taking into consideration the conditions necessary for maintaining nitrogen equilibrium and for providing the body with essential amino acids, it is now generally believed that the diet should contain about 1 gram of protein per kilogram of body weight per day (60 to 90 grams for an adult). This amount is considered ample to maintain an individual in nitrogen equilibrium and to provide sufficient essential amino acids under practically all conditions of food intake.

Metabolism of Inorganic Salts

The inorganic salts do not contribute any energy to the body, but are necessary for correct metabolism. Sodium, potassium, calcium, magnesium, iron, chlorides, sulfates, phos-

phates, and carbonates are present in all the tissues of the body, and are essential to life. Small amounts of iodine, fluorine, copper, manganese, aluminum, zinc, tin, arsenic, and silicon are also constituents of the human body. About 25 grams of inorganic salts are consumed per day, normally, and about one-half of this amount is sodium chloride. We will discuss briefly the metabolism of each of the inorganic elements that are known to be essential for correct nutrition.

Sodium and Potassium.—Salts of sodium and potassium are essential in the diet. Osborne and Mendel found that when the sodium and potassium of the diet of rats were reduced until the content of each was below 0.03 per cent, the animals would not grow. Thus it was demonstrated that *sodium and potassium are essential for growth.*

The salts of sodium and potassium are necessary to maintain the irritability of muscle and nerve tissues; they also aid in the maintenance of the osmotic pressure equilibrium of the tissues. Sodium and potassium ions are responsible for a considerable part of the carbon dioxide carrying-power of the blood and for the neutralization, transportation, and elimination by way of the kidneys, of appreciable amounts of acid radicals.

Potassium compounds are found in all food supplies in amounts that are adequate to satisfy the nutritive requirements of the body. There is considerable sodium in the usual foods, and this source, together with the sodium chloride that is added voluntarily to the food, supplies the needs of the body, except in very hot weather when the ingestion of additional sodium chloride may become desirable.

Calcium.—Certain salts of calcium, namely, the phosphate, the carbonate, and the fluoride, are highly insoluble in a neutral or alkaline medium. These compounds are, therefore, readily adaptable to the formation of structural and supporting tissues in the animal body. Of the 50 to 60 per cent of mineral matter in bone, calcium phosphate makes up about 85 per cent, calcium carbonate about 10 per cent, and calcium fluoride about 1 per cent. The cement and dentine of the teeth have essentially the same calcium composition as bone, and about 90 per cent of the enamel of the teeth

consists of calcium compounds, a composition which accounts for the unusual hardness of this substance. *Calcium thus has an important role in supplying material for the skeletal growth of the young and for the maintenance of the composition of the hard tissues of both the young and the adult.*

Calcium ions are also essential for the clotting of blood and the coagulation of casein following the digestive action of rennin.

Calcium ions have a sedative influence upon the motor nervous system. The normal calcium concentration of the blood is from 9 to 11 mg. per 100 c.c. of serum. If a condition develops which reduces the serum calcium concentration below normal, varying degrees of hyperexcitability result, and tetany usually occurs when the level of blood calcium gets below 7 mg. per 100 c.c. of serum. *Calcium ions are also concerned in the regulation of heart action,* the influence of calcium being balanced by the antagonistic effects of sodium and potassium.

The amount of calcium in the diet has an important influence upon growth and upon the maintenance of a well-nourished condition of the bones and teeth. The Food and Nutrition Board of the National Research Council has recommended that the daily allowance of calcium should be 0.8 gram for adults and 1 gram for children; and that the daily intake of calcium should be 1.5 grams during pregnancy and 2 grams during lactation. To offset the unusual drains upon the maternal organism during pregnancy and lactation, many physicians prescribe the administration of calcium salts in addition to the use of a liberal diet.

The body does not conserve its calcium in periods of calcium deprivation or calcium starvation, but apparently continues to excrete this substance at the usual rate. If the calcium of the diet is reduced below minimum requirements, the blood calcium will remain at a normal level for a considerable time, due to the withdrawal of calcium from the bones by the action of the secretion of the parathyroid glands; continued deprivation of calcium, however, will bring about a decalcification of the bones and a lowered calcium

content of the blood. The outcome of such a dietary deficiency is rickets in children and osteomalacia in adults.

Magnesium.—*Magnesium compounds make up about 1 per cent of the mineral constituents of the bones and teeth. Magnesium also exists in small quantities in the soft tissues of the body and in the body fluids. The magnesium ion has a sedative effect.*

That magnesium is an element essential to life has been shown by experiments in which rats were fed on low magnesium diets. From such investigations McCollum and his associates found that young rats upon a diet containing not over 1.8 parts of magnesium per million parts of food do not survive. Within three to five days after being placed upon such a diet, there is a marked vasodilatation. Later there is hyperexcitability of the nervous system resulting in a form of tetany. The heartbeat becomes rapid and irregular. The animals have recurring convulsions and finally die. Such experiments as these show the indispensability of magnesium in the diet. Apparently the foods of all peoples of the world contain an ample amount of this element to supply the needs of the human body.

Iron and Copper.—*Iron is essential for the production of hemoglobin and for certain other vital functions. Recently it has been found that copper has an important role in the formation of red blood cells and hemoglobin.* When iron alone is added to a diet low in iron and copper, there is a poor response in red cell and hemoglobin production; but, if small amounts of copper, in addition to the iron supplement, are added to an anemia-producing diet, a marked regeneration of red cells and hemoglobin occurs.

Milk does not contain enough iron and copper to bring about normal hemoglobin regeneration. Young rats placed on a diet of milk alone develop an anemia, referred to in the literature as "nutritional" anemia. The addition of iron only to the milk diet will not cure this anemia, but the feeding of 0.01 to 0.02 mg. of copper per rat per day, in addition to the iron supplements, brings about a rapid restoration to normal of the red cells and hemoglobin of the blood.

At birth the infant has a reserve supply of iron and copper stored in its body, which it utilizes during the early periods of life while upon an exclusive milk diet. If continued upon a diet of milk alone, the infant will also develop a nutritional anemia. It is, therefore, necessary, beginning about 6 to 8 months after birth, to supplement the milk diet of the infant with some foods containing iron and copper, to prevent nutritional anemia.

According to Sherman, the iron requirement of the adult is about 15 milligrams per day. About the same amount has been found desirable to meet the growth and maintenance requirements of children. The iron requirements would be much greater if it were not for the body's unusual capacity to conserve its iron.

Manganese.—Manganese is indispensable for the development of plants and it is essential in the diet of at least several species of animals. *In animals, it has been found necessary for growth, reproduction, the proper development of bone and the activity of a number of enzymes.*

Mice on a low manganese diet failed to grow as well as control animals receiving adequate amounts of manganese.

A high mortality was observed in the young of female rats on a low manganese diet. Apparently manganese is necessary for the development of the fetus during gestation. Male rats upon a manganese-free diet develop a testicular degeneration which results in sterility.

In the fowl, the need for manganese is as great as in mammals. Eggs from hens on a low manganese diet showed a hatachability of less than 10 per cent, and the embryos of those eggs that hatched were poorly developed. On a low manganese diet, chickens develop perosis or "leg-weakness." In this condition, the tendon of the knee joint slips from its normal position, producing a crippling deformity.

Laboratory experiments have shown that manganese is necessary for the activity of a number of enzymes of animal and plant tissues.

In view of all the evidence it seems extremely probable that manganese is an indispensable constituent of the diet of man.

Manganese is poisonous if ingested in abnormal amounts.

Zinc.—Zinc is necessary for the growth of both plants and animals. Many foods contain small amounts of zinc.

Zinc is a constituent of crystalline insulin and of carbonic anhydrase, an enzyme in the red blood cells that stimulates the liberation of carbon dioxide from bicarbonate. It is found in the pancreas in larger amounts than in any other tissue.

Zinc is poisonous if taken into the body in unusual amounts. Poisoning may result from the oral ingestion of zinc salts, or from the inhalation of particles of zinc oxide or zinc dust.

Iodine.—*Iodine is an essential constituent of thyroxin, the active substance of the thyroid gland. If iodine is not present in the diet in adequate amounts, simple goiter results.* This condition is discussed later, in the section on Thyroxin (page 359). It has been estimated that the diet should contain about 0.05 milligram of iodine per day to meet the needs of the body.

Chlorine.—The element chlorine occurs in the body in the form of the chloride. It is present in all tissues. *Chlorides participate in the maintenance of the osmotic pressure equilibrium of the tissues and of the water balance of the body. Chlorides are also source materials used in the production of the hydrochloric acid of gastric juice.*

The amount of chlorides excreted in twenty-four hours by the normal human subject varies from 5 to 15 grams, expressed as sodium chloride. A part of this salt is in the food ingested, but a considerable portion is added to the diet voluntarily. The amount of sodium chloride consumed is apparently in excess of the basic metabolic needs of the body, and its overingestion is probably a result of the desire for its condiment effect.

In a time of salt deprivation, or excessive losses of salts from the body, as in high intestinal obstruction which causes vomiting, or in pneumonia in which there are heavy losses of salt in the fluid exudate from the lungs, the body conserves its salt supply by diminishing the chloride excretion

in the urine. The capacity of the body for protection against salt losses, or inadequate salt intake, is limited. In conditions in which there is body depletion of salt from pathological processes, it is a therapeutic practice to replace salt losses by the administration of sodium chloride.

Fluorine.—In the human body fluorine is found in very small amounts in the soft tissues and in slightly higher concentrations in the bones and teeth. Bone contains about 0.01 to 0.02 per cent and tooth enamel about 0.03 per cent of this element.

Fluorine is toxic to the body if ingested in appreciable quantities. The fluoride ion precipitates the calcium of the blood and it inhibits the activity of a number of the body's enzymes. Cases of fatal poisoning from the ingestion of fluoride (a common ingredient of certain roach exterminator powders) have occurred. Obviously this element could not be tolerated in the food or drinking water if present in appreciable quantities.

Fluorine occurs in many foods and in the drinking water of many communities in small amounts. The content in the food and water is usually related to the amount in the soil of the community. When the food contains more than 10 mg. per 100 grams, or the drinking water has in it more than 2 parts per million (0.2 mg. per 100 c.c.) of this element, a defect in the enamel of the teeth, called "mottled enamel," develops in children who ingest such food or water at the time the permanent teeth are being formed. "Mottled enamel," also called *fluorosis,* is a condition characterized by chalky-white patches in the enamel of the teeth. It has been produced experimentally in rats by placing fluorides in the drinking water.

Recent investigations have shown that small amounts of fluorides in the food and drinking water may be beneficial by preventing dental caries. Dean and his associates in the United States Public Health Service observed relatively few cases of dental caries in communities where the drinking water contains more than 0.5 part of fluorides per million parts of water. These authors also found a low incidence of

"mottled enamel" in regions where the drinking water did not contain more than 1.2 parts of fluorides per million parts of water. Thus, with regard to the well-being of the teeth, it would seem ideal to have drinking water of a fluoride concentration ranging from 0.5 to 1.2 parts per million and foods of a related fluoride content. Such conditions would be expected to produce a minimum of dental caries and at the same time would not result in the existence of "mottled enamel."

Sulfur and Phosphorus.—We have previously noted that *a sulfur-containing amino acid, methionine, is essential in the diet to bring about growth and proper nutrition (page 281).* When the sulfur-containing compounds of the body are oxidized, sulfates are formed. Sulfates may be considered as waste products of the body. They are excreted continuously in the urine. Before being eliminated from the body, however, they are of use in contributing to the osmotic balance of body fluids, and they may be conjugated with phenols, or other toxic substances, thereby assisting in detoxifying and removing the latter from the body.

Phosphorus is a constituent of the mineral phosphates of the bones and teeth, and of the soft tissues of the body and the body fluids. The phosphates also participate in carbohydrate metabolism, in the contraction of muscle, and in the maintenance of the acid-base and osmotic pressure balances of the tissues. Obviously there must be a liberal source of phosphorus in the diet. According to Sherman, the phosphorus requirement of the adult is about 0.88 gram per day. In examining the dietaries of American families, Sherman found that only 4 per cent fell below this amount. A nutritional disorder in cattle, due to a deficiency of phosphorus in the cattle food that is grown on a soil low in phosphorus, has been observed in South Africa.

Questions for Study

1. What is metabolism?
2. Define anabolism. Catabolism.
3. Describe the anabolism of carbohydrates.

4. What is the normal amount of glucose in the blood? How high does the blood sugar rise following a carbohydrate meal? What does the body do with this increased blood sugar normally?

5. How much glycogen is in the whole body when well nourished?

6. What is the chief source of energy used for the mechanical movements of the body?

7. What is the immediate cause of diabetes mellitus? What changes are found in the blood and urine in diabetes?

8. What factors determine the amount of carbohydrate that should be in the diet?

9. Describe the anabolism of fats?

10. What are the functions of fats?

11. Describe the metabolism of the acetone bodies.

12. What ratio of fat to carbohydrate in the diet will prevent the production of excess acetone bodies?

13. What is acidosis?

14. Name the three essential fatty acids.

15. Describe the anabolism of proteins.

16. What are the functions of proteins in metabolism?

17. Are proteins stored in the body? Can they be converted to carbohydrates?

18. In calculating a diabetic diet, what per cent of protein is considered as carbohydrate?

19. What becomes of the amino acids that are in excess of the requirements of the body for tissue construction?

20. What is meant by nitrogen equilibrium in the body? Positive nitrogen balance? Negative nitrogen balance?

21. What protein foods have the highest nutritional value to man? Explain.

22. What are essential amino acids? Name them.

23. What is a satisfactory protein intake per day?

24. What are the functions of sodium and potassium in the animal body?

25. What are the uses of calcium in the body?

26. What amount of calcium should be in the diet of a normal adult? Of a child?

27. Discuss the calcium requirements during pregnancy and lactation.

28. What diseases result from a dietary deficiency of calcium?

29. What are the uses of magnesium in the body?

30. Describe the condition in rats resulting from a low magnesium diet.

31. What is the nutritive value of iron? Copper?

32. Why does a secondary anemia result from a diet consisting exclusively of milk?

33. What is the iron requirement per day?

34. What conditions will develop in animals upon a low manganese diet?

35. What information is there to show that zinc is an essential constituent of the diet?

36. What is the physiological importance of iodine?

37. Mention the uses of chlorides in the body.

38. What pathological processes result in abnormal losses of chlorides from the body?

39. What concentration of fluorine in the drinking water will produce "mottled enamel" of the teeth?

40. Below what concentration of fluorine in the drinking water does dental caries occur in relatively large amounts?

41. Discuss the metabolism of sulfur in the animal body.

42. What are the metabolic functions of phosphorus?

CHAPTER XXX

ENERGY METABOLISM

Calorimetry.—The human body is capable of doing work, for which it requires fuel. The fuels used are proteins, carbohydrates, and fats. In the body the latter substances undergo chemical degradation through the activity of enzymes, as shown in previous chapters, and release their energy slowly. The energy which the body obtains from the chemical breakdown of food substances is used to carry on its living processes, such as respiration, heartbeat, muscle tonus, and the muscular movements producing work.

In order to measure the energy transformations that constantly take place in the body, we must establish a satisfactory unit of measurement. Just as we use the meter to measure length, or the gram to measure weight, or the second to measure time, so we must have a standard unit for measuring metabolism. It might seem difficult at first to select a single unit to measure such a varied process as metabolism, but energy, while manifested in several forms, is really a single entity that can be estimated by measuring one of its several manifestations. The form of energy that is measured in studying metabolism is heat, and the Calorie, a heat-measuring unit, is, therefore, the unit used in the measurement of metabolism. The large Calorie is the one used for this purpose. It will be recalled that this Calorie is the amount of heat necessary to raise one kilogram of water 1° Centigrade.

The energy value of foods is determined with an instrument called the "bomb" calorimeter, which gets its name from the fact that it is shaped like a bomb. This instrument is a steel cylinder, which can be sealed tightly and immersed in a vessel of water whose temperature can be measured by delicate thermometers. When a test is to be made, food and oxygen are introduced into the apparatus, and it is closed tightly. An electric current is then passed through a platinum wire in contact with the food, which heats the wire to

redness and ignites the food. The food is oxidized completely, and the heat liberated is estimated by the temperature change in the water surrounding the bomb, knowing, of course, the thermal equivalent of the bomb and the amount of water in the vessel.

The heat liberated by foods burned in the human body, or in the body of an animal, may be determined by an interesting application of calorimetry. There are two general methods of calorimetric measurement used with animals or human subjects, namely, the direct and the indirect. Direct calorimeters involve the same principle of heat measurement as the bomb calorimeter. One of the best direct calorimeters consists of a large double-walled copper chamber, surrounded by cooling water pipes, in which the temperature of the water can be taken as it enters and leaves the system. Appropriate devices for supplying measured amounts of oxygen for respiration, and for removing and measuring carbon dioxide and water vapor, are connected with the chamber. In such an instrument, an individual can be placed and his heat output determined while fasting, or after being fed any kind of food; while lying down, or in a sitting position; or while doing work of graded types of severity.

Indirect calorimetry involves the use of instruments that measure the oxygen consumption and carbon dioxide output of an individual for a given time. From such data, together with the urinary nitrogen and facts obtained by laboratory experimentation, the heat production in the body can be calculated. The Atwater-Rosa-Benedict calorimeter is a combination of both the direct and the indirect systems of measurement. With this calorimeter its inventors secured remarkably close agreement in the results obtained by the direct and indirect methods of calorimetry.

It has been found by investigators that carbohydrates and fats, when burned in the human body, have the same calorie value as when burned in a bomb calorimeter. Proteins, however, show a higher calorie value when burned in a bomb calorimeter than when oxidized in the body. This is explained by the fact that the nitrogen of proteins is not ox-

idized in the human body but is oxidized in the bomb calorimeter, and the oxidation of nitrogen liberates heat. If we deduct the amount of heat due to the oxidation of nitrogen when proteins are burned in a bomb calorimeter, we get the same value as obtained from the burning of proteins in the body. The law of the conservation of energy, therefore, holds good for the energy exchanges that take place in the human body.

The rate of metabolism may be expressed as the number of Calories per kilogram of body weight, or as the number of Calories per square meter of body surface. The relationship to body surface is generally used, since it gives more satisfactory information in comparing individuals of widely differing sizes. The total metabolism of the body is expressed in terms of the number of Calories of heat produced in the body as a whole. The total metabolism of the human being ranges from 2,200 to 10,000 Calories per twenty-four hours. Metabolism is influenced by many factors, the most important of which are outlined below.

Factors Affecting the Rate of Metabolism

1. **Activity.**—The factor that affects the rate of metabolism the most is activity. The more work an individual does, the greater will be the oxidation of foods in his body to supply the needed energy. Persons engaged in sedentary work have a metabolism of 2,200 to 2,800 Calories per twenty-four hours. In the same period of time a carpenter will average around 3,400 Calories, and very hard laborers may have a metabolic activity as high as 5,000 or 6,000 Calories.

2. **Age.**—Metabolism is much higher in the young than in the old. The metabolic rate shows a gradual decline after the second year until old age is reached. The greater rate in the young is due to greater activity and to the requirements of growth, and to difference in size.

3. **Size.**—Metabolism varies according to size. The more surface an individual has, the greater will be the amount of heat radiated from his body. Hence the metabolic rate is roughly proportional to the body surface. The more surface

per unit of weight, the higher the rate of metabolism will be. The metabolic rate is, therefore, higher in a small individual than in a large one, other factors being equal.

4. **Food.**—The ingestion of foods brings about an increase in metabolism. In this respect the three classes of food substances vary widely. Carbohydrates, when ingested, will increase the rate of metabolism an average value of about 6 per cent; fats will increase the metabolic rate about 12 per cent; and proteins stimulate the rate of metabolism about 30 per cent. The acceleration of metabolism by foods is known as their *specific dynamic action.* A high protein diet will reduce body weight because proteins stimulate the rate of metabolism (specific dynamic action), bringing about an increased burning of food and tissues in the body.

5. **Glandular Secretions.**—The secretions of the endocrine organs have a regulatory influence upon metabolism. The secretion of the thyroid, for instance, has a stimulating influence. A hyperthyroid individual shows a high metabolic rate, and a hypothyroid subject has a subnormal metabolism. For this reason, the determination of an individual's basal metabolism is an important aid in the diagnosis of thyroid conditions.

Basal Metabolism

The basal metabolism is the metabolic activity of the body, twelve to fifteen hours after the last meal, while the individual is awake, comfortably warm and at complete rest. It represents the lowest amount of chemical changes that take place in the body in a relaxed position, the subject being awake, in a comfortable environment, at complete rest, and free from the influence of food. It is the energy production necessary for the maintenance of a state of tonus in the muscles; for the movements of the chest and the diaphragm in respiration; for the heartbeat and muscular contractions involving other internal organs; in short, for all the life processes that take place when the subject is living under the conditions mentioned above. *The normal basal metabolic rate of the male adult between the ages of 20 and 40 years is 39*

Calories per square meter of body surface per hour. In the case of the adult female at the same ages the rate is lower, being about 36 Calories per square meter of body surface per hour. For a twenty-four-hour period the average basal metabolism of a normal adult is about 1,680 Calories.

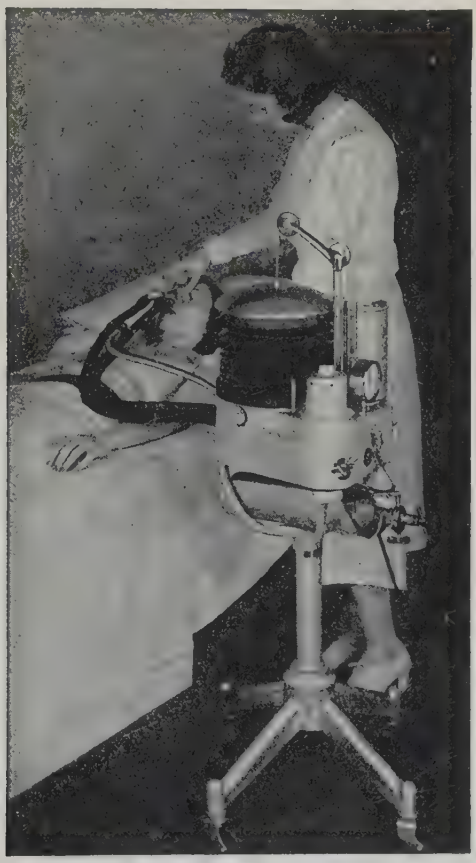


Fig. 36.—Basal metabolism determination. (Courtesy of the Sanborn Co.)

A basal metabolism determination is made with the individual lying at rest about fifteen hours after the ingestion of food. The determination consists of measuring the number of liters of pure oxygen consumed by the individual in a definite time and converting the value obtained to the amount that would

be consumed in one hour. Since the oxidation brought about by 1 liter of oxygen in a normal individual at complete rest produces 4.83 Calories of heat, the calculation consists of multiplying the number of liters of oxygen consumed per hour by 4.83. This value represents the total number of Calories of heat produced per hour. When the latter is divided by the number of square meters of body surface of the individual (obtained from height-weight tables of data), the basal metabolic rate, which is the number of Calories per square meter of body surface per hour, is obtained.

Questions for Study

1. How does the human body obtain energy?
2. What unit is used to measure metabolism?
3. What is a bomb calorimeter? For what is it used?
4. Describe a direct calorimeter used for measuring the metabolism of the body.
5. What are the procedures used in indirect calorimetry?
6. Do carbohydrates and fats yield the same heat when oxidized in the body as when burned in a bomb calorimeter?
7. Explain why proteins yield more heat when oxidized in a bomb calorimeter than when oxidized in the body.
8. What are the factors which change the rate of metabolism?
9. Why will a high protein diet reduce body weight?
10. What is basal metabolism?
11. What is the average basal metabolism in terms of Calories?
12. What is the metabolism of a person engaged in sedentary work? Of a carpenter? Of a very hard laborer?
13. Describe a basal metabolism determination.

UNIT XIV

THE CHEMISTRY OF EXCRETION

CHAPTER XXXI

URINE, SWEAT, BILE AND FECES

Channels of Excretion.—The removal of the waste products of metabolism of the body is accomplished by the lungs, the kidneys, the skin, the intestines and the liver. The elimination of carbon dioxide and water through the lungs is discussed in the chapter on Respiration (Chapter XXXIII). The excretory processes that take place through the other eliminatory organs will be discussed briefly.

Excretion Through the Kidneys

Urine.—The kidneys excrete the waste product known as urine. The urine is a solution of inorganic salts and organic waste products of metabolism, consisting of about 96 per cent water and 4 per cent solids. It is a very important excretion. It contains practically all of the nitrogenous waste products of the body, the nonvolatile acids produced in metabolism, the excess inorganic salts not needed by the body, and many other metabolic end products that would be toxic to the body if retained in the tissues.

The amount of urine excreted by a normal adult in twenty-four hours varies from 800 to 1,800 c.c. The quantity excreted is influenced greatly by climate. In warm weather the volume of urine is low because of the increased elimination of water through the skin in the sweat. In cold weather the elimination of water by sweating is reduced, and as a consequence there is a marked increase in the volume of urine excreted.

The color of urine varies from light yellow to dark brown. The color of urine is due to the presence of pigments, the

principal ones being urobilin, uroerythrin, and urochrome. In general, the depth of color of urine is proportional to the concentration. Dilute urines are more or less pale in color, while concentrated urines are highly colored.

The odor of urine is faintly aromatic when freshly voided. Upon standing it tends to become ammoniacal due to decomposition of nitrogenous substances by bacterial action.

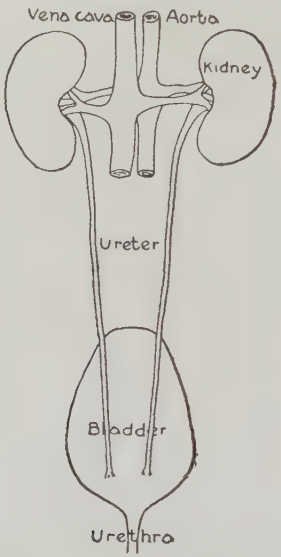


Fig. 37.—Diagram of urinary system. (From Pearce and Macleod: *Fundamentals of Human Physiology*, The C. V. Mosby Company.)

The odor may be influenced somewhat by food or drug ingestion and by disease. Thus the ingestion of asparagus imparts the peculiar odor of methyl mercaptan to urine, and the urine in diabetes mellitus sometimes has a fruity odor due to the presence of acetone and acetoacetic acid.

The urine normally contains a few white blood cells, an occasional red blood cell, and a small amount of epithelial cells due to desquamation of tissue from the urinary tract. The amount of cellular material in urine may be great enough to give the urine a cloudy appearance. Whether

the cloudy appearance has any significance is revealed by a microscopic examination.

The urine may be turbid, due to the presence of certain substances that have crystallized or precipitated from solution. These substances appear because of the development of conditions that lower their solubility after the sample is voided, such as a decrease in the temperature of the specimen, or ammoniacal decomposition which makes the urine more alkaline. Of these substances, phosphates, amorphous urates, crystals of uric acid, and calcium oxalate occur most commonly. Phosphates may occur either in the crystalline or the amorphous state. They are found in the form of sediment principally in alkaline or neutral urines, sometimes in a very faintly acid urine. Amorphous urates occur in acid urines, appearing as "brick-dust" deposits. Uric acid crystals will often form in acid urines upon standing. Calcium oxalate crystals are sometimes found in neutral or very faintly acid urines. These substances do not have any pathological significance. Turbidity in a sample of urine due to their presence is considered normal, except that phosphates might possibly indicate an abnormally alkaline urine.

The specific gravity of urine is related to the amount voided. In general, the greater the volume excreted, the lower will be the specific gravity. Taking into account the variations in amount excreted, a specific gravity of 1.008 to 1.030 is generally considered normal.

The reaction of urine is determined by the diet. A diet of proteins will make the urine acid, while a diet of fruits and vegetables tends to make the urine alkaline. The reaction of the urine of man is normally acid. This is because man is naturally a carnivorous animal, eating a considerable amount of meats which are largely proteins. In general, the urine of carnivorous animals is acid in reaction and that of herbivorous animals is alkaline.

The more important normal constituents of urine are outlined on the following page:

ORGANIC CONSTITUENTS	INORGANIC CONSTITUENTS
Urea	Water, about 96 per cent
Uric acid	
Creatine	
Creatinine	
Amino acids	Chlorides, Sulfates, Phosphates, Bicarbonates of Ammonium, Sodium, Potassium, Calcium, Magnesium, Iron
Glucose	
Lactic acid	
Pigments: Urobilin, Uroerythrin, Urochrome	
Hippuric acid	
Thiocyanic acid	
Glycuronic acid	
Oxalic acid	
Indican	
Vitamins	
Hormones	

Abnormal Constituents of Urine.—

1. *Proteins.*—Normally the urine does not contain proteins. If proteins are found in the urine in amounts sufficient to give the usual qualitative chemical tests, pathology in the urinary tract is usually indicated. The proteins most often encountered in urine under pathological conditions are albumin and globulin. These proteins are the serum albumin and serum globulin of the blood, which pass through the kidneys when the latter are not functioning properly. These two proteins are generally considered under the name albumin, since the globulin occurs less frequently and in smaller amounts than the albumin, and when found in urine it has the same significance as albumin. Albuminuria usually indicates the existence of a nephritis or a nephrosis, diseased conditions of the kidneys due to inflammatory or degenerative changes. Albuminuria may also be found in cases of inflammation in the urinary tract below the kidneys, such as a cystitis, or inflammation of the bladder, in which there is a discharge of protein material into the urine. Renal albuminuria is practically always accompanied by the occurrence of tube casts in the urine.

Albuminuria may sometimes occur that is not pathological. Thus there may be albuminuria due to severe muscular exercise; there may also be the form known as orthostatic, or postural, albuminuria, which appears after the subject has

stood on his feet for several hours, and disappears after rest in bed. The latter is believed to be due to a stasis of blood in the kidneys that occurs during standing.

2. *Sugar.*—The urine normally contains about 0.02 to 0.04 per cent of sugar. This amount will not give the usual qualitative tests for sugar, such as Benedict's or Fehling's tests. In abnormal conditions of carbohydrate metabolism, sugar is excreted in the urine in amounts readily detected by the usual tests. The sugar found in the urine under abnormal conditions is nearly always glucose, and this condition is called glucosuria. Glucosuria is in nearly all cases the result of hyperglycemia, or increased blood sugar. Occasionally subjects are observed, however, who excrete sugar in the urine when the blood sugar is within normal limits. Such subjects are said to have a low sugar threshold, and the condition is known as renal diabetes.

Glucosuria is a characteristic finding in diabetes mellitus. Moderate glucosuria may also occur from the ingestion of a very large quantity of carbohydrate, and from worry, fright, or nervous excitement.

Lactose is sometimes excreted in the urine during late pregnancy and lactation. Lactosuria is not a pathological condition and is of interest principally because it may lead to a mistaken diagnosis of glucosuria by the usual urine tests for sugar.

3. *Acetone Bodies.*—The acetone bodies are acetone, acetoacetic acid and β-hydroxybutyric acid. They appear in the urine as a result of incomplete oxidation of fatty acids, due to a failure to utilize carbohydrates. They are found in the urine in diabetes mellitus, in carbohydrate starvation, and when the fat content of the diet is too high, that is, when there is more than 1.5 grams of fat to 1 gram of carbohydrate in the diet. Acetone bodies may also be found in the urine following general anesthesia.

The acetone bodies are acid in character. When formed in the tissues, they require alkalies to neutralize them before they are excreted in the urine. Hence the production

of acetone bodies reduces the fixed alkalies of the body and thus produces an acidosis. The finding of acetone bodies in the urine is, therefore, an indication that an acidosis of greater or less degree exists.

4. *Increased Indican.*—Indican is a metabolic product formed in the liver by a combination of the sulfate radical with indole, a substance produced in the intestinal tract by bacterial action upon the amino acid, tryptophane. The quantity of this substance excreted in the urine is considered a measure of the amount of bacterial action upon amino acids in general in the intestinal tract. A little indican in the urine is considered normal. When found in the urine in increased quantities, it indicates that excessive putrefaction is taking place in the intestinal tract.

5. *Bile.*—Bile is normally excreted through the intestine along with the feces. When found in the urine, it indicates the existence of an obstruction to the flow of bile into the intestine. Such obstruction may be due to a calculus, a neoplasm, or a catarrhal inflammation, which would interfere with the flow of bile through the bile ducts; or it may be due to severe liver damage. Examination of the urine for bile has little clinical application, as there are more sensitive tests for biliary dysfunction, such as examination of the blood serum for bile pigments, which gives earlier and more reliable indications of existing pathology.

6. *Blood.*—The finding of blood in the urine usually indicates a lesion in the urinary tract. The most common causes of blood appearing in the urine are acute nephritis, stone in the kidneys or bladder, renal tuberculosis, and tumors in the urinary passages. The chemical tests for blood are exceedingly sensitive and are used largely to corroborate the finding of red blood cells in the microscopic examination.

Excretion Through the Skin

Sweat.—Sweating is one of the body's methods of getting rid of heat and waste products. When water is passed from the interior to the surface of the body it conveys with it the heat that was absorbed in bringing it to body temperature.

When water appears on the surface of the skin, the body loses more heat by converting this water in the liquid state into water vapor. The vaporization of 1 c.c. of water from the surface of the body requires 0.58 Calories of heat. The body eliminates about 25 per cent of its heat through this imperceptible, or "insensible," vaporization of water from the skin. Some heat is eliminated in the same way through the lungs.

The vigor of the sweating process is determined by the temperature and the activity of the body. Any factor which increases metabolism will increase heat output. An increase in temperature within the body or in the environment will speed up metabolism and produce more sweating. Increased bodily activity also accelerates metabolism and heat production and hence brings about a greater elimination of heat through the sweating process.

The evaporation of water from the surface of the skin is influenced by the relative humidity of the atmosphere. In a dry atmosphere sweat is readily vaporized and heat elimination is thus facilitated. On the other hand, when the relative humidity is high, vaporization of water from the skin is not as rapid and consequently this heat elimination process of the body is less effective. This explains why a high relative humidity upon hot days results in so much discomfort to the body.

Sweating is a process by which the body excretes some products of metabolism for which it has no further use. Under average conditions of temperature and humidity, the average normal man excretes about 450 c.c. of sweat per day. The sweat is a dilute solution of products of metabolism and inorganic salts. The following substances have been found in the sweat:

1. Water, about 99 per cent.
2. Inorganic Salts

Sodium, Potassium, Ammonium	Chlorides or Phosphates
Calcium, Magnesium	Sulfates or Phosphates

3. Organic Constituents

Urea
Uric acid
Creatinine
Creatine
Amino acids
Sugar
Lactic acid
Traces of water soluble vitamins

Sweat is slightly acid, the pH ranging from 5.2 to 7.3. The specific gravity is 1.002 to 1.003. The largest single constituent is sodium chloride of which there is an average content of about 0.5 per cent. The next largest constituent is urea of which there is about 0.05 per cent. The amounts of amino acids, sugar and water soluble vitamins are very small and do not represent appreciable losses of nutritive substances. The excretion of lactic acid is useful as a means of maintaining the acid-base balance of the body, especially during severe exercise.

From the above discussion it is clear that all of the substances found in sweat also occur in urine. The urine contains these substances in a much greater concentration, however. Thus the excretion of sweat by the skin is a function similar to that performed by the kidneys in the excretion of urine.

In summary, it is to be said that sweating is a process by which the body eliminates about one-fourth of its heat and also appreciable amounts of waste products of metabolism.

Excretion Through the Liver

Bile.—Bile, the substance excreted through the liver, is both a secretion and an excretion. It is a secretion in the sense that it contains substances that aid in the digestion and absorption of foods, thereby performing a physiological function. It is an excretion in that it contains a number of substances which are true waste products having no further function in the body.

The composition of bile is as follows:

Water, 85 to 95 per cent
Pigments: Bilirubin
Biliverdin
Bile salts (Taurocholates, Glycocholates)
Bile soaps (salts of fatty acids)
Cholesterol
Lecithin
Mucin
Sex hormones
Inorganic salts:

Sodium, Potassium	Chlorides, Sulfates
Calcium, Magnesium	Phosphates
Ammonium	Bicarbonates

Bile may be stored for a time in the gall bladder, or it may pass directly from the liver through the bile ducts into the small intestine. It is emptied into the small intestine near the lower end of the duodenum and, after considerable transformations, the residual products are finally excreted in the feces.

The origin of bilirubin, the parent substance of the bile pigments, is from broken-down red blood corpuscles. It has been estimated from bile excretion studies that the human body destroys about 1,000,000,000,000 red corpuscles per day. When red blood corpuscles disintegrate, their hemoglobin is broken down into globin and protohematin. Iron is removed from the protohematin, and the latter substance is finally converted into bilirubin. These chemical changes take place principally in the bone marrow and the spleen. The bilirubin thus formed passes from the blood stream into the liver where it is altered slightly. It is finally excreted in the bile.

Excretion Through the Intestine

Feces.—The excretory products formed in, and eliminated through, the intestinal tract are called feces. The fecal substances originating in the intestine are undigested food residues, food substances that have escaped absorption, the

remains of digestive secretions, mucus, water, and a very large number of living and dead bacteria, also products of bacterial action upon foods and food residues. These substances are true excretions, but would not be considered waste products of body metabolism, since their origin and existence are entirely within the alimentary canal, and they have not entered into the chemical processes taking place in the body tissues. The fecal materials which originate in the tissues and are excreted by way of the intestine consist of inorganic salts, notably calcium and magnesium phosphates and salts of iron, a small amount of nitrogenous substances, and bile; these substances represent true waste products of metabolism, since they are formed in the metabolic processes that take place in the body tissues.

Functional failure in the organs of digestion, as a result of disease, is often revealed by the appearance of the feces. Thus, in disease of the liver or biliary tract in which there is obstruction to the flow of bile, digestion in the intestine will be less complete because of the absence of bile. Since bile is necessary for the digestion of fats, the failure of bile to appear in the intestinal tract will cause a marked increase in the fat content of the stools. Excesses of fat in the intestinal tract tend to interfere with the digestion of proteins and carbohydrates because food particles become coated with fat films which prevent the action of proteolytic and carbohydrate-splitting enzymes. As bile pigments color the stools brown, the absence of bile from the intestinal tract causes the feces to appear white in color. Hence, chalky-white feces, with an increased fat content, indicate the presence of obstructive pathology in the biliary system.

In like manner, disease in the pancreas which interferes with the production of pancreatic juice, or the flow of the latter into the intestinal tract, has an unfavorable effect upon digestion in several ways. The most obvious failure is in the digestion of proteins because of a diminished supply of proteolytic enzymes. This results in meat fibers and increased amounts of undigested proteins in the feces. There is also interference with fat digestion in pancreatic dysfunction because of a diminished secretion of the enzyme, steap-

sin; hence the stools will have a high fat content in this condition. Starch digestion is also less successful in the intestinal tract in disease restricting the function of the pancreas because of a decreased output of amylopsin. This causes undigested starch grains to appear in the feces. Thus, a bulky stool, of high fat content and containing undigested meat fibers and starch grains, is suggestive of disease interfering with the production of pancreatic juice or the flow of the latter into the intestinal tract.

Questions for Study

1. Through what organs are the waste products of the body eliminated?
2. What is the normal amount of urine excreted per 24 hours?
3. What substances may make the urine turbid? Is their presence normal?
4. What is the specific gravity of normal urine?
5. What foods make the urine acid? What foods may make it alkaline?
6. Name the more important constituents of the urine.
7. What does the finding of albumin in the urine usually indicate?
8. What is the significance of glucose in the urine?
9. What is the interpretation of lactosuria?
10. What would produce acetone bodies in the urine?
11. What does increased indican in the urine indicate?
12. What pathology would cause bile to appear in the urine?
13. What conditions would cause blood to appear in the urine?
14. What are the principal constituents of sweat? In what way does sweat resemble urine?
15. What functions are accomplished by the process of sweating?
16. In what respects is bile a secretion? An excretion?
17. What is the origin of the bile pigments?
18. What substances are excreted through the intestine?
19. In what ways may the appearance of the feces indicate pathology in the biliary system? In the intestinal tract?

UNIT XV

THE BLOOD AND RESPIRATION

CHAPTER XXXII

THE BLOOD

The blood is a circulating tissue. It consists of a fluid part, called the plasma, and certain cellular or formed elements uniformly distributed in the plasma. The formed elements of the blood are the red cells or erythrocytes, the white cells or leucocytes, and the platelets. In human blood the average number of red cells per cubic millimeter is from 4,500,000 to 5,000,000; of white cells, from 5,000 to 10,000; and of platelets, from 300,000 to 800,000. The total amount of blood in the body is about 8.8 per cent of the body weight.

The principal chemical constituents of the blood are water, proteins, amino acids, glucose, lipids, inorganic salts, waste products of metabolism, hormones, vitamins, and enzymes. A detailed composition of the blood is given in Table XII.

TABLE XII

Water, 75 to 80 per cent

Proteins, about 20 per cent:

- Hemoglobin
- Fibrinogen
- Serum albumin
- Serum globulin

Carbohydrate—Glucose, about 0.1 per cent

Lipids, 1 to 2 per cent:

- Fats
- Cholesterol
- Lecithin

Inorganic Salts, about 2 per cent:

Chlorides Sulfates Phosphates Bicarbonates	of	Sodium Potassium Calcium Magnesium Iron

Waste Products, about 0.5 per cent:

Carbon dioxide
Urea
Uric acid
Creatine
Creatinine
Ammonia

Enzymes:

Catalase
Amylase
Maltase
Protease
Lipase
Antibodies

Functions of the Blood.—

1. The blood carries food materials from the intestines to the tissues and oxygen from the lungs to the tissues. The food materials are carried in solution; the oxygen is carried in combination with the hemoglobin of the red cells as oxyhemoglobin.

2. The blood carries waste products of metabolism from the tissues to the excretory organs of the body (kidneys, lungs, skin, intestine).

3. The blood distributes internal secretions (hormones) to their appropriate sites of action.

4. The blood defends the body against the invasion of parasites. This function is carried out by the immune bodies, the manner of action of which is not well known, and by the leucocytes, which ingest and destroy the pathogenic organisms.

5. The blood, in circulating, brings about a uniform distribution of heat. Hence it aids in the regulation of body temperature.

Coagulation of Blood.—The coagulation, or clotting, of blood is a mechanism designed to prevent the loss of blood from the body when some point in the closed system of vessels, in which it circulates, is ruptured. The elements which form the clot exist in the blood and in the tissues surrounding the blood vessels. In the blood there are fibrinogen, calcium salts, prothrombin and antithrombin, a substance which prevents clotting. In the blood platelets and the tissues there is a sub-

stance called thromboplastin that facilitates clotting. When a blood vessel is cut, blood is shed and becomes mixed with the surrounding tissues. Under these conditions thromboplastin is liberated from the platelets and the cut tissues. Thromboplastin in the presence of calcium salts reacts with prothrombin to produce thrombin. Thrombin finally acts upon the fibrinogen of the blood, forming fibrin, the insoluble threadlike mass of protein that enmeshes the blood cells and forms the clot.

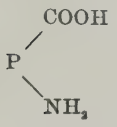
As noted above, calcium ions are essential for the coagulation of blood. We may, therefore, prevent the coagulation of drawn samples of blood by adding some substance that will precipitate the calcium ions from solution. If it is desired to obtain a sample of blood in the uncoagulated state, it is only necessary to add some calcium precipitant, like potassium oxalate or sodium fluoride, to prevent coagulation. This is why a little powdered potassium or sodium oxalate is placed in the bottles or tubes in which blood is collected for chemical analysis.

Sodium citrate also prevents the coagulation of blood because the citrate ion combines with the calcium ion to form un-ionized calcium citrate and thus the calcium is converted into a form which prevents its entering into the clotting process. Sodium citrate is, therefore, used to prevent coagulation of blood in blood transfusions or in blood bank work.

Acid-Base Balance of the Blood—Buffers.—The normal pH of the blood is around 7.4. This means that blood is very slightly alkaline. Normally the pH of the blood remains constant. If the pH of the blood reaches 7.3 to 7.0, the subject has a marked acidosis; and when the pH is 7.5 to 7.8, an alkalosis exists. The blood is able to maintain a fairly constant pH, even though a considerable amount of acid or base is introduced into the animal's body. This remarkable property of the blood is due to the presence of certain substances called buffers.

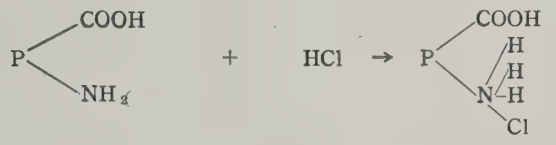
A buffer is a substance which resists a change in the pH of a solution. The buffers of the blood are proteins, amino

acids, bicarbonates, and phosphates. Amino acids are effective buffers, but there is relatively a small amount of these substances in blood. The proteins are far more effective because the blood contains a large amount of them. Proteins behave as buffers because of their ability to neutralize either acid or base. We learned in the chapter on proteins that these substances consist of amino acids, and that amino acids contain amino groups which will neutralize acids, and carboxyl groups which will neutralize bases. Thus, letting

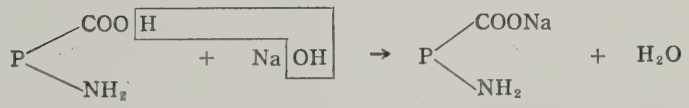


stand for the protein molecule, we may have either of the two following reactions taking place:

(a)



(b)



In reaction (a) acid is neutralized, and in reaction (b) base is neutralized.

Bicarbonates act as buffers against acidity by reacting with a strong acid to produce carbonic acid, H_2CO_3, which is a weak acid. For example, if the strong acid, HCl, is added to a solution containing sodium bicarbonate, the following change occurs:

$$NaHCO_3 + HCl \rightleftarrows NaCl + H_2CO_3$$

In this reaction the strong acid, HCl, is replaced by H_2CO_3, which is so weak an acid that there is very little change in the pH of the solution. Sodium bicarbonate thus serves as a buffer, preventing increases in acidity of the solution which would occur if it were not present.

Phosphates are effective buffers against either acid or base. For examples, let us consider the following two reactions:

(a) Na_2HPO_4 (Disodium phosphate) + $HCl \rightleftarrows NaCl$ + NaH_2PO_4 (Monosodium phosphate)

(b) NaH_2PO_4 (Monosodium phosphate) + $NaOH \rightleftarrows H_2O$ + Na_2HPO_4 (Disodium phosphate)

In reaction (a) the strong acid HCl is replaced by the acid salt, NaH_2PO_4, which is an acid, it is true, but is much weaker than HCl. Hence disodium phosphate serves to resist the increase in the acidity of the solution which would result from the addition of the HCl in the absence of the phosphate. In reaction (b) the phosphate behaves in an opposite way. The strong base, NaOH, is replaced by the weakly basic disodium phosphate, and thus a marked shift toward alkalinity in the solution is avoided by the presence of the phosphate.

The story of buffers, as told for the blood, is the same for all of the tissues of the body. Without its buffers, the human body (or the body of an animal) could never withstand the acids produced in metabolism, or the excesses of acids or bases that are sometimes encountered as a result of accidental intake of extra acid or base, or the abnormal amounts of acid or base sometimes resulting from an unbalanced diet, or disease.

The kidneys are able to produce ammonia which may serve to neutralize acids. The renal production of ammonia is thus an additional buffering defense of the body against acidity.

Application of Blood Chemistry to the Diagnosis of Disease.—With the development of simple methods of analysis, blood chemistry has become an invaluable aid to the physician in the diagnosis of disease. This application of chemistry is based upon the fact that the blood in many diseases undergoes changes in composition that are characteristic of the disease present.

To obtain chemical blood findings that may be used in diagnosis, it is necessary to collect the blood after the patient has fasted for about fifteen hours. This is done by taking the sample of blood in the morning before the patient has eaten breakfast. Blood collected under these conditions has been found to give values upon chemical analysis that show very little variation in normal subjects of the same species. By analyzing the blood of a large number of normal human subjects collected after a fifteen-hour fast, we are able to establish a value for each of the constituents of the blood which would be considered normal for human blood.

Having obtained normal values for each of the constituents of human blood, we find it an easy matter to interpret variations from the normal in terms of pathology. For example, the blood sugar of a normal individual has been found to be within the limits of 65 to 100 mg. per 100 c.c. of blood under fasting conditions. If a sample of blood is collected from a patient in the morning before breakfast and the chemical analysis of this sample shows a blood sugar higher than 130 mg. per 100 c.c., a diabetic condition is usually indicated. Likewise it is known from chemical analysis of normal bloods that the nonprotein nitrogen constituents of the blood (waste products of protein and purine metabolism) make a total of 25 to 35 mg. of nitrogen per 100 c.c. If the blood chemistry of a patient shows that the nonprotein nitrogen is above 40 mg. per 100 c.c. of blood under fasting conditions, this patient is not eliminating nitrogenous waste products properly, and kidney disease or other elimination disorders are indicated. These are illustrations of the numerous instances where, knowing the normal composition of blood under fasting conditions, a diagnosis of a diseased condition may be made from the blood chemistry when a variation from the normal values is obtained.

Questions for Study

1. What is blood plasma? What are the formed elements of the blood?
2. What is the average number of red cells per cubic millimeter of human blood? Of white cells? Of platelets?
3. Name the principal chemical constituents of blood.

4. What are the functions of blood?

5. What are the elements that enter into the formation of a blood clot? Describe the coagulation of blood.

6. What is a buffer? Name the buffers of the blood.

7. How does the body resist the introduction of excesses of acids or bases?

8. Why is potassium or sodium oxalate placed in the containers in which blood is collected for a blood chemistry?

9. Why is sodium citrate solution mixed with blood for blood transfusions?

10. How are normal values for the composition of the blood obtained?

11. Under what conditions are samples of blood collected for blood analysis?

12. Explain how blood chemistry is used in the practice of medicine.

13. What would be the interpretation of a blood chemistry report showing a blood sugar of 200 mg. per 100 c.c. of blood? A blood non-protein nitrogen of 80 mg. per 100 c.c.?

CHAPTER XXXIII

RESPIRATION

General Discussion.—Pure air contains about 20 per cent oxygen, 79 per cent nitrogen and 0.03 to 0.04 per cent carbon dioxide. When air is breathed into the lungs and retained there for a fraction of a minute, a considerable change in composition occurs. The air that is expired from the lungs of a human subject contains about 16 per cent oxygen, 79 per cent nitrogen and 4 per cent carbon dioxide. In other words, as a result of its passage into and out of the lungs, the air loses approximately 4 per cent of oxygen and gains about 4 per cent of carbon dioxide. The nitrogen content of the air remains constant during breathing because nitrogen does not enter into chemical reactions in the body.

The oxygen decrease in air during respiration results from a diffusion of this element through the thin membranes of the lung alveoli into the blood capillaries where it combines with hemoglobin to form oxyhemoglobin. The carbon dioxide increase arises from the diffusion of carbon dioxide from the blood into the lungs as the blood passes through the capillaries of the lung alveoli. Respiration in the lungs then is essentially an exchange of gases across the thin membranes of the lung alveoli: oxygen is passed from the lungs into the blood where it combines with hemoglobin; and carbon dioxide is released from compounds in the blood that hold it in loose chemical combination and diffuses into the lungs.

Further consideration of respiration involves a discussion of the mechanisms which enable the blood to carry oxygen from the lungs to the tissues and carbon dioxide from the tissues to the lungs.

The Transportation of Oxygen by the Blood.—As stated above, oxygen passes from the air in the lungs into the blood of the alveolar capillaries and combines with hemoglobin to form oxyhemoglobin. About 99 per cent of the oxygen used

by the body is carried to the tissues by hemoglobin, the remaining 1 per cent being carried in solution in the blood plasma.

Three factors operate to facilitate the combination of oxygen with hemoglobin. In the first place, the pressure under which oxygen exists in the lungs is greater than in the blood and tissues. In the lung alveoli, oxygen has a pressure that will raise the mercury in a manometer to a height of about 100 millimeters. The oxygen in arterial blood is held under a tension equal to about 80 millimeters of mercury and the oxygen in the fluids surrounding the capillaries in the tissues is under a pressure of 20 to 40 millimeters of mercury. The greater pressure of oxygen in the lungs physically promotes the passage of this gas from the lung alveoli into the blood and its combination therein with hemoglobin. On the other hand, the low oxygen tension in the tissues is favorable for the dissociation of oxyhemoglobin into hemoglobin and oxygen. Thus the high oxygen pressure in the lungs favors the uptake of oxygen by hemoglobin in the pulmonary blood and the low oxygen pressure in the tissues is favorable to the release of oxygen from oxyhemoglobin in the sites where oxygen is needed.

When a patient is given pure oxygen, the increased oxygen pressure is an important factor in the success of this treatment. In the oxygen tent the patient breathes almost pure oxygen. This means that the pressure of oxygen as a gas in the lungs is several times greater when pure oxygen is inhaled than when air is breathed. The increased oxygen pressure does two things: it promotes the uptake of oxygen by hemoglobin and it brings a greater amount of oxygen into solution in the blood plasma. Both of these factors enable the patient to obtain a better supply of oxygen in the tissues.

A second factor influencing the uptake of oxygen by hemoglobin is the pH of the blood. A shift of pH toward the alkaline side favors combination of oxygen with hemoglobin and a shift of pH toward the acid side favors the dissociation of oxyhemoglobin into hemoglobin and molecular oxygen. In the lungs the blood pH shifts toward the

alkaline side because CO_2 is given off, hence the combination of oxygen with hemoglobin is promoted here. In the tissues, the pH of the blood changes toward the acid side because CO_2 is taken up by the blood; this favors the release of oxygen from oxyhemoglobin. Thus, the shift of the pH of the blood toward alkalinity in the lung capillaries favors the uptake of oxygen from the pulmonary alveoli and the shift of pH toward acidity in the tissues promotes the release of oxygen from oxyhemoglobin in those regions where oxygen is needed.

A third factor of importance in respiration is temperature. The lowering of the temperature of the blood as it passes through the lung capillaries promotes the combination of oxygen with hemoglobin. In the tissues the temperature of the blood becomes slightly warmer, an influence that favors the dissociation of oxyhemoglobin. Thus the cooling of the blood in the lungs promotes the uptake of oxygen by hemoglobin and the warming of the blood in the tissues favors the release of oxygen from oxyhemoglobin in sites where this element is needed.

The Transportation of Carbon Dioxide by the Blood.— Carbon dioxide is one of the end products of the oxidation of foodstuffs in the body. It is carried away from the tissues by the blood. The substances that assist in this process in blood are bicarbonates, carbonates and proteins. The part played by bicarbonates may be illustrated by the following equations Let B stand for any basic ion.

In the tissues and blood:

$$\underset{\text{Carbonate}}{B_2CO_3} + H_2O + CO_2 \rightarrow 2\ \underset{\text{Bicarbonate}}{BHCO_3}$$

In the lungs:

$$2\ \underset{\text{Bicarbonate}}{BHCO_3} \rightarrow \underset{\text{Carbonate}}{B_2CO_3} + H_2O + CO_2$$

In the above equations it is shown that the carbon dioxide in the tissues combines with basic carbonate to form bicarbonate; this takes place because there is an increased pressure of CO_2 in the tissues where it is being continuously produced. The bicarbonate is transported in the blood to the lungs where it

decomposes, forming carbonate and carbon dioxide. The decomposition of bicarbonates in the lungs is favored by the decreased pressure of CO_2; it is also promoted by an enzyme in the red cells called *carbonic anhydrase.* The carbon dioxide diffuses through the thin walls of the lung capillaries into the alveoli and is removed by respiration. The bicarbonates of the blood thus serve as continuous carriers of carbon dioxide from the tissues to the lungs.

Proteins assist in the transportation of carbon dioxide in two ways: they yield basic ions (chiefly sodium and potassium) to combine with carbon dioxide and form carbonates and bicarbonates, as shown above; and carbon dioxide will combine with the amino group of the protein molecule to form a protein-carbamino compound. The latter compound releases its carbon dioxide as it passes through the lung capillaries and thus serves as a carrier of carbon dioxide from the tissues to the lungs. This process is illustrated by the following equations.

In the blood of peripheral tissues:

$$P.NH_2 + CO_2 \rightarrow P.NH\ COOH$$

Protein — Protein carbamino compound

In the blood of the lung capillaries:

$$P.NH\ COOH \rightarrow P.NH_2 + CO_2$$

A small amount of carbon dioxide is physically dissolved in blood plasma. The amount carried by the blood in this way is about 5 to 10 per cent of the total transportation.

Thus, the transportation of carbon dioxide from the tissues to the lungs is accomplished by the blood through the activity of its bicarbonates and proteins, and through its physically dissolved carbon dioxide. The bicarbonates assume the major role in this process; the proteins are second in importance; and the amount carried in solution is third in order of quantitative significance.

Tissue Respiration.—In the animal body, energy is obtained by the oxidation of the hydrogen of carbohydrates, fats, proteins, or other compounds that may serve as foods. *The oxidations that take place in the tissues are brought about through the activity of enzymes. Molecular oxygen*

does not combine directly with foods. The essential problem in tissue respiration is to bring molecular oxygen into combination with the hydrogen of foodstuffs.

In the tissues, there are *oxidases,* or enzymes that combine with molecular oxygen and activate it to the extent that it will combine with the hydrogen of foods. The tissues also contain enzymes, called *dehydrogenases,* which remove hydrogen from the molecules of foodstuffs. A third general group of enzymes exists in tissues, whose function is to serve as *"carriers"* of hydrogen between the dehydrogenases and oxidases.

A broad picture of tissue respiration is as follows. Dehydrogenases remove hydrogen from foodstuffs and transfer this hydrogen to enzymes that serve as carriers. The carriers bring their hydrogen into active contact with the oxygen that has been made reactive by the oxidases and finally water is formed. *Thus, as a result of the activity of dehydrogenases, carriers and oxidases, molecular oxygen of the air is made to react with the hydrogen of foodstuffs to form water, a reaction that liberates energy.*

Questions for Study

1. What changes occur in the composition of the air that is breathed into and out of the lungs in a normal manner?
2. What causes the decrease in oxygen in the lung alveoli? The increase in carbon dioxide?
3. How is oxygen transported from the lungs to the tissues?
4. Explain how the differences in the pressure of oxygen as a gas favor the uptake of oxygen in the lungs and its release from oxyhemoglobin in the tissues.
5. Give two reasons why the administration of pure oxygen enables the patient to get a better supply of oxygen in the tissues.
6. How do changes in the pH of the blood influence the combination of oxygen with hemoglobin?
7. How do changes in the temperature of the blood affect oxygen uptake in the lungs and oxygen release from oxyhemoglobin in the tissues?
8. What are the carriers of carbon dioxide in the blood?
9. Explain how bicarbonates serve as carriers of carbon dioxide from the tissues to the lungs.
10. How do proteins function as carriers of carbon dioxide?
11. What basic ions are the more important in the transportation of carbon dioxide?

12. What protein of the blood is the most important protein carrier of carbon dioxide?

13. Is any carbon dioxide carried by the blood in solution as carbonic acid?

14. In the body, energy is obtained from the oxidation of what element in foodstuffs?

15. How is molecular oxygen made to combine with the hydrogen of foods?

16. Give a general discussion of the processes that take place in tissue respiration.

UNIT XVI

MILK AND FOODS

CHAPTER XXXIV

MILK

Milk is the secretion of the mammary glands of mammals. As the food designed by Nature for the nourishment of the newborn, it is an excellent nutritive substance. It has all the constituents of a correct diet, and in practically balanced quantities, with the exception of being deficient in iron, copper, and vitamins C and D. The average energy value of cow's milk containing 4 per cent of butter fat is about 675 Calories per quart.

The milks of all species of animals have essentially the same constituents, but vary considerably in the relative amounts of these constituents. This variation has an important influence upon the rate of growth of each species. In general, the speed of growth of the young varies in direct proportion to the richness of the milk in proteins and inorganic salts: the higher the content of proteins and inorganic salts in the milk of any species, the more rapid is the rate of growth of that species.

The Principal Constituents of Milk.—The gross constituents of milk are shown in Table XIII. It will be of interest to discuss these substances a little more in detail.

The proteins of milk are casein, lactalbumin, and lactoglobulin. Casein is a phosphoprotein. It makes up about 80 per cent of the total protein content. These three proteins are entirely adequate for the nutrition of an animal in so far as protein requirement is concerned.

The carbohydrate of milk is lactose. This sugar does not occur anywhere except in milk. It is synthesized by the mammary gland from the glucose of the blood.

The fats of milk consist of glycerol esters of all of the fatty acids mentioned in the chapter on Fats. These are butyrin, caproin, caprylin, caprin, laurin, myristin, palmitin, stearin, and olein.

The principal inorganic constituents of milk are salts of calcium, potassium, sodium, magnesium, phosphorus, and chlorine. Iron and copper are present, though not in amounts adequate for the nutrition of the young. Milk is a rich dietary source of calcium and phosphorus.

Milk contains all of the vitamins necessary for the nutrition of the species producing it. Cow's milk, however, contains only one-third as much vitamin C as human milk, and as a result of standing and pasteurization its vitamin C content is reduced. Cow's milk is thus inadequate in vitamin C for human nutrition; and during the months of the year when there is reduced exposure to sunshine, it does not contain enough vitamin D for the human infant.

The average composition of human milk and of cow's milk is as shown in Table XIII.

TABLE XIII

CONSTITUENT	HUMAN MILK PER CENT	COW'S MILK PER CENT
Water	84—88	84—88
Proteins	1—2	3.5—4
Carbohydrate: Lactose	6.5—8	3.5—5
Fat	3—5	3—5
Inorganic salts	0.15—0.3	0.6—0.7

Preparation of Cow's Milk for Infant Feeding.—In Table XIII it is shown why cow's milk is usually diluted before feeding it to the human infant. The protein content of cow's milk is about three times as high as it is in human milk. When used for infant feeding, cow's milk is, therefore, diluted with enough water to bring the protein content to about the same relative quantity as found in hu-

man milk. The addition of water, however, reduces the carbohydrate content of cow's milk, and cow's milk is normally lower in percentage of lactose than human milk. Carbohydrate must, therefore, be added to the diluted milk. This is done by introducing lactose or dextrimaltose in amounts that will make the carbohydrate content of the diluted cow's milk equivalent to the normal carbohydrate content of human milk.

Supplying the Food Deficiencies of Milk.—As mentioned above, cow's milk is deficient in vitamin C, and does not contain enough vitamin D to prevent rickets in children during the time of the year when there is limited exposure to sunlight. Milk is also deficient in iron and copper. Severe anemia may be produced in animals by feeding them an exclusive milk diet; a child will develop a secondary anemia if fed upon milk only for a considerable time.

The nutritional deficiencies of milk must receive attention in the feeding of infants. At birth the infant has stored in its body enough vitamins, copper, and iron to meet its nutritional requirements for a short period of time. But soon after birth it is necessary to supplement the milk diet with simple foods containing the nutritive principles that are lacking in milk. To provide the necessary vitamin C, it is the practice to give orange juice or tomato juice or crystalline vitamin C to the infant within about six weeks after birth. Vitamin D is supplied by giving cod-liver oil or a vitamin D concentrate about seven or eight weeks after birth. The necessity for additional iron and copper is provided for by supplementing the milk diet with eggs and purées of green vegetables, beginning about seven months after birth.

Souring of Milk.—Milk becomes sour upon standing, due to the production of lactic acid by the action of certain bacteria upon lactose. When milk sours, the casein separates from solution as an insoluble curd, a change which is due to the lactic acid formed. Casein may be precipitated from milk by very small amounts of other acids, and by the action of rennin. When casein is removed from milk by acids or by rennin, it carries with it considerable fat and traces of

other constituents of milk. This combined mixture of casein, fat, and other substances is known as "cream cheese." The casein mixture prepared from milk is the basis of the various cheeses that are widely used as foods.

Pasteurization.—In principle, pasteurization of milk consists of heating the milk to a temperature that will kill most bacteria, and then cooling it rapidly. Pasteurization is carried out most successfully by keeping the milk at 65° C. for thirty to forty minutes, and then chilling it promptly to low temperatures. *A satisfactory milk should not contain more than 200,000 bacteria per cubic centimeter before pasteurization, and after pasteurization it should contain less than 10,000 bacteria per cubic centimeter.*

Questions for Study

1. Discuss the value of milk as a food.
2. What is the relation of composition of milk to the rate of growth of different species of animals?
3. Compare the composition of human milk with that of cow's milk.
4. How is cow's milk made suitable for infant feeding?
5. How is the milk diet of the infant made adequate in vitamins C and D?
6. How are copper and iron supplied in the diet of the infant?
7. How does the souring of milk occur?
8. What is "cream cheese"?
9. How is milk pasteurized? What is the permissible number of bacteria in milk that is considered safe for consumption?

CHAPTER XXXV

FOODS

Definition of a Food.—A food is best defined in terms of the functions it serves in the body. In the first place, we may say that a food is a substance that is used for the production of body tissues. This means that foods are substances which bring about growth of the body in the case of the young, and the repair, or renewal, of the tissues of the body in both the young and in the adult. Such substances as proteins, carbohydrates, fats, inorganic salts, and water are used in this capacity.

The production of energy by their oxidation in the body is also an important function of foods. This use of foods is limited almost wholly to proteins, carbohydrates, and fats. In presenting this idea it should be cautioned that not all substances which would liberate energy, if oxidized in the body, may be considered as foods; in fact, many substances that are actual poisons, e.g., the alcohols or morphine, may be oxidized in the body with the liberation of energy. Nevertheless, the capacity to liberate energy, when oxidized in the body, must be considered as one of the characteristics of a food.

A third characteristic of foods is their capacity to promote correct metabolism. Certain inorganic salts, water, oxygen, and vitamins are foods in this sense.

Bearing in mind the principles mentioned above, we may define foods as *substances which are of use to the body in (1) the formation of tissues, (2) the liberation of energy by their oxidation, and (3) the promotion of correct metabolism.*

Composition of Foods.—In this course it seems desirable for the student to acquire a general knowledge of the composition of foods. Such information need not be detailed, but it is important for the student to be able to tell whether a food is composed principally of proteins, or of carbohydrates, or of fats, or of combinations of these; also whether

it contains essential mineral constituents and vitamins. The following tabulations have been prepared to give a general idea of the character of the common foods:

Foods Rich in Proteins:

Lean meats; eggs; cheeses of all kinds; gelatin; peas; beans; soybeans; wheat; corn; breads; oatmeal; nuts.

Foods Rich in Carbohydrates:

Cane sugar; maple sugar; glucose; syrups; sugar products, such as candies, pastries, preserves, jellies; wheat; wheat products, such as cereals, flour, bread, cakes, and crackers; corn; corn products, such as cereals and corn bread; rice; tapioca; oatmeal; macaroni; beans; peas; potatoes; fruits, especially oranges, bananas, grapes, apples, pineapple; nuts.

Foods Rich in Fats:

Butter; lard; Crisco; oleomargarine; cream; bacon; fat meats; cheeses of all kinds, except cottage cheese; nuts; olive oil; Wesson oil; peanut butter; cocoa; chocolate.

Foods Rich in Calcium:

Cheese; milk; almonds; hazelnuts; beans; figs; olives; cauliflower; cocoa; chocolate; peas; walnuts; celery; peanuts; oatmeal; spinach; eggs; turnips; oysters; carrots; oranges; cabbage; wheat; rye.

Foods Rich in Iron:

Lean meats; oysters; spinach; beans; peas; wheat; barley; rye; hazelnuts; oatmeal; eggs; dates; prunes; corn; chocolate; cocoa.

Foods Rich in Vitamins:

Vitamin A: Animal fats, such as butter, fish liver oils; milk; eggs.

Provitamin A: Leafy vegetables, such as kale, spinach, broccoli, cabbage, lettuce; carrots; apricots; sweet potatoes.

Vitamin B_1*:* Yeast; pork; whole wheat; unpolished rice; beans; oatmeal; nuts; liver; kidney; meats; milk.

Riboflavin: Yeast; liver; kidney; milk; eggs; cheese; meats; beans; peas; greens of all kinds; strawberries; almonds; peanuts; pecans.

Vitamin C: Peppers; kale; cabbage; broccoli; cauliflower; spinach; lemons; oranges; grapefruit; limes; pineapple; potatoes; turnips; tomatoes; onions; peas.

Vitamin D: Animal fats, such as cod-liver oil, butter, lard; milk; liver; eggs; oysters; clams.

Vitamin E: Wheat; wheat germ oil; corn; oats; lettuce; spinach; water cress; kale; alfalfa; meats.

Foods of Value for Their Bulk (Fiber Content):

Lettuce; spinach; cabbage; kale; broccoli; beets; asparagus; cauliflower; celery; carrots; squash; tomatoes; melons; string beans; fruits.

Acid-Forming Foods:

Bread; meats; eggs; oatmeal; rice; wheat; cranberries; prunes; plums; cakes; crackers.

Base-Forming Foods:

Apples; oranges; grapefruit; bananas; lemons; raisins; asparagus; beans; beets; cabbage; cantaloupe; carrots; cauliflower; celery; lettuce; potatoes; milk.

Acid-Forming and Base-Forming Foods.—An acid-forming food is one that produces more acid than base when metabolized in the body. A base-forming food is one that produces more base than acid when metabolized in the body.

The normal metabolism of carbohydrates and fats does not change the acid-base balance of the body. When carbohydrates and fats are oxidized in the body, carbon dioxide and water are formed. Carbon dioxide is a very weak acid and is rapidly eliminated from the body. Most of the carbon dioxide, when eliminated, passes out through the lungs as a gas, and leaves in the blood the basic ions which were used to neutralize it temporarily and to transport it to the lungs. The production and transportation of carbon dioxide thus do not bring about any appreciable loss of base from the body; hence, the influence of carbon dioxide production upon

the reaction of the body tissues is negligible. The formation of water has no influence, since water is neutral. Therefore, the oxidation of carbohydrates and fats has practically no influence upon the acid-base balance in the body.

The metabolism of proteins results in acid production. When proteins are oxidized in the body, carbon dioxide, water, urea, ammonium salts, sulfuric and phosphoric acids are produced. The oxidation of proteins produces more acid than base, because the sulfuric and phosphoric acids formed overbalance the neutralizing capacity of the ammonia produced. The excess of sulfuric and phosphoric acids is neutralized by basic ions and eliminated in the urine, a process which results in loss of base from the body. The end result of the metabolism of proteins, then, is the production of acidity. Therefore, foods rich in proteins are acid-forming foods.

The base-forming foods are fruits and vegetables. This often seems paradoxical to the student. It is at first difficult to understand why fruits or vegetables, which have an acid reaction when taken into the alimentary tract, really have base-forming tendencies when they undergo metabolism in the tissues. The explanation of this situation lies in considering the nature of the foods and what happens to the foods when oxidized. The acids of fruits and vegetables are organic acids, most of which are readily oxidized in the body. When oxidized in the body, they form carbon dioxide and water. The latter products, as we noted above, have a negligible influence upon the reaction of the body tissues; hence the acids of fruits or vegetables lose their acid characteristics when metabolized in the body. On the other hand, there are basic elements in fruits and vegetables that are in combination with the organic acids or other organic compounds. When the organic part of the molecules of these compounds is oxidized, the basic elements are left free to act as basic ions. Examples of basic ions liberated in the tissues in this way are sodium, potassium, calcium, magnesium, and ammonium. The liberation of these ions in metabolism increases the free base content of the tissues and, therefore, accounts for the base-forming characteristic of fruits and vegetables.

A few fruits, e.g., cranberries, prunes, and plums, are acid-forming foods. This is because they contain benzoic acid, an organic acid that cannot be oxidized in the body and gives rise to the formation of hippuric acid. Hippuric acid has an acid influence in the tissues and renders the urine acid. Thus fruits containing considerable benzoic acid are exceptions to the general principle that fruits are base-forming foods.

Calorie Value of Foods.—Nothing is gained by attempting to learn the exact calorie value of foods. When one wants to know the fuel value of a food, tables of food values are consulted. Nevertheless, it is quite worth while to have a general idea of the energy value of foods. A general knowledge of the calorie value of foods may be obtained without memorizing data by studying carefully Table XIV on page 330. This table was prepared for purposes of discussion and study. In this table representative common foods have been divided arbitrarily into 3 classes as follows: (1) foods of high fuel value, above 2,000 Calories per pound; (2) foods of intermediate fuel value, between 1,000 and 2,000 Calories per pound; (3) foods of low fuel value, below 1,000 Calories per pound. A study of this table will reveal certain general principles of interest. In the first place, it will be noted that the foods of high fuel value are fats, or substances rich in fats, such as nuts, chocolate, and American cheese. This fits into our previously acquired knowledge that fats have the highest calorie value of all food substances, namely, 9 Calories per gram. The next observation from this table is that in general the foods of intermediate fuel value are meats of considerable fat content, and foods rich in starches or sugars, such as beans, macaroni, grains, sugar, and honey. The third fact revealed by this table is that in general the foods of low fuel value are lean meats, milk, fruits, and the leafy and green vegetables. The lean meats consist of 10 to 25 per cent of protein, practically no carbohydrate, and small amounts of fat; they have a high water content which is the reason why they fall in the low-calorie class of foodstuffs. Milk contains appreciable amounts of protein, carbohydrate, and fat, but its high water content (84 to 88 per cent) is responsible for this food being in the

TABLE XIV

FUEL VALUE	FOOD	CALORIES PER POUND
HIGH FUEL VALUE	Lard	4080
	Butter	3491
	English walnuts	3199
	Brazil nuts	3162
	Almonds	2940
	Bacon	2840
	Chocolate	2768
	Peanuts	2490
	American cheese	2102
INTERMEDIATE FUEL VALUE	Sugar	1815
	Oatmeal	1811
	Wheat	1635
	Macaroni	1625
	Corn meal	1620
	Rice	1591
	Beans, dried	1565
	Mutton	1543
	Pork chops	1530
	Honey	1481
	Fresh ham	1458
	Olives	1357
	Lamb, breast	1311
	Apple pie	1233
	Beef, Porterhouse steak	1230
	White bread	1182
LOW FUEL VALUE	Veal, breast	817
	Liver, beef	583
	Chicken	493
	Sweet corn, fresh	459
	Potatoes, white	378
	Milk, whole	314
	Pears	288
	Apples	285
	Grapefruit	235
	Oranges	233
	Oysters	228
	Carrots	204
	Peaches	188
	String beans	184
	Beets	180
	Muskmelon	180
	Cabbage	143
	Cauliflower	135
	Pumpkin	117
	Spinach	109
	Tomatoes	104
	Lettuce	87
	Celery	84
	Cucumbers	79

class of low fuel values. The fruits and the leafy and green vegetables consist of small amounts of protein, fat, and carbohydrate, and a large percentage of water (around 90 per cent). The small amount of oxidizable substances and the large content of water in the fruits and the leafy and green vegetables also account for the low calorie value of these foodstuffs.

From the preceding discussion we may state in summary the following rather obvious conclusions concerning the fuel value of foods. *Foods rich in fats have a high calorie value. Foods rich in starches or sugars have an intermediate calorie value. The calorie value of foods varies inversely with the water content; the higher the water content, the lower is the calorie value.*

Questions for Study

1. Define a food.
2. Name six foods that are rich in proteins.
3. Name six foods that are rich in carbohydrates.
4. Name six foods that are rich in fats.
5. Name several foods that are rich in calcium; in iron.
6. Name several foods that are rich in vitamin A. In vitamin B_1. In riboflavin. In vitamin C. In vitamin D. In vitamin E.
7. What is meant by foods of value for their bulk? Name several foods of this type.
8. Name several acid-forming foods. Several base-forming foods.
9. Explain why certain foods are acid forming. Why certain foods are base forming.
10. Why are prunes, plums, and cranberries acid forming?
11. Name several foods of high fuel value. Of intermediate fuel value. Of low fuel value.
12. Give three guiding principles that will aid one in forming an estimate of the fuel value of a food.

UNIT XVII

VITAMINS AND HORMONES

CHAPTER XXXVI

VITAMINS

Introduction

It is probably justifiable to say that the science of nutrition had its beginning in systematic efforts to learn the effect of different food substances when fed to small animals. In such experiments rats, mice, and guinea pigs have been most useful, because such animals have a rapid span of life and consume relatively small amounts of food substances; and usually, although not always, the results obtained with these animals may be interpreted to apply similarly to the human being. The general procedure has been to prepare a diet of known purified constituents in known amounts. Such an artificially prepared diet will be called a synthetic diet in this discussion. This diet is fed to small animals and its effects upon the growth and general well-being of the animals are noted. It is very interesting that the early attempts to maintain mice and rats upon an artificially prepared diet resulted in complete failure; animals fed such diets did not live. We know now that their failure to survive was due to the absence from the diet of the substances we call vitamins.

The term "vitamin" arose from a suggestion made in 1912 by Funk, who intended to incorporate in a name for these unknown dietary constituents the idea that they are vital, or essential for life, and that they are amines; hence, the name "vitamine" was proposed. Later, when the chemistry of the vitamins became better known, it was found that the meaning of this term did not fit the chemical nature of these substances, but the name was retained for its convenience, the terminal letter "e" of Funk's designation being dropped to form the term "vitamin."

The earliest significant experiments in the search for vitamins were those made in Switzerland in 1888 by Lunin, who fed mice a synthetic diet of foodstuffs prepared in the laboratory by chemical methods. Upon this diet, consisting of proteins, carbohydrates, fats and inorganic salts, the animals did not survive. When milk was added, the animals lived. In interpreting his experiments this investigator expressed the view that there are unknown substances in milk which must be present in the diet of an animal to maintain life. These highly suggestive laboratory experiments received little attention until Pekelharing, in the Netherlands in 1905, repeated them, and confirmed the correctness of Lunin's observations; Pekelharing found also that he could maintain life in the mice receiving synthetic diets by giving them milk to drink instead of water. Hopkins, in England in 1906, published work showing that rats would not survive when fed a highly purified food mixture consisting of casein, starch, cane sugar, lard, and inorganic salts. When milk was added to this diet, the rats lived and grew well. Thus it was demonstrated by feeding experiments with synthetic diets prepared from purified ingredients that there are substances in milk, small in amounts and presumably not proteins, carbohydrates, fats, or inorganic salts, which must be present in the diet to maintain life. These observations, together with others to be mentioned later, led to the discovery of the highly important dietary constituents which we call vitamins.

Vitamin A.—In 1913, McCollum and Davis, and Osborne and Mendel independently announced results of experiments showing that there is a substance in butter fat which promotes the growth and well-being of rats. These investigators found that rats would not grow on a synthetic diet in which lard was used as the source of fat, but when butter was substituted for lard the animals grew well and remained in good health. Thus it was revealed for the first time that there is a fat-soluble dietary substance which is essential for satisfactory nutrition of animals. This substance was first called "fat-soluble A" factor and is known as vitamin A.

Vitamin A is found in butter, cod-liver oil, milk, eggs, liver, and animal fats in general. Substances giving rise to vitamin A (precursors) also occur in these sources and are especially prevalent in green and yellow vegetables.

Vitamin A has several functions in the body. In the first place it must be present in the diet to obtain growth of the young. This function need not be thought of as characteristic, as probably any food deficiency resulting in disordered health will retard growth.

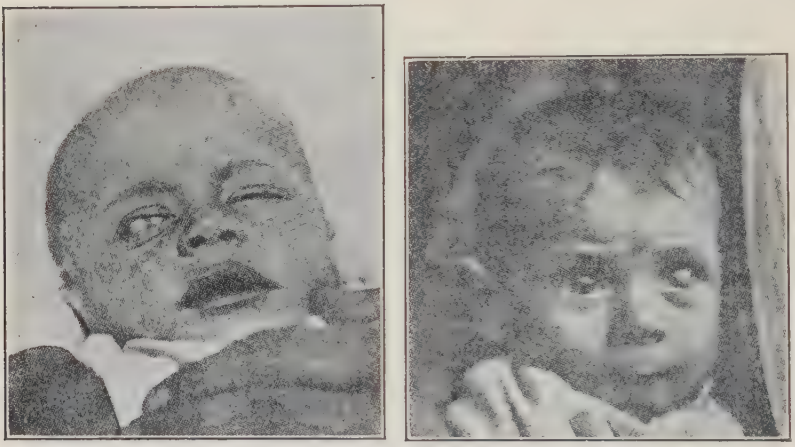


Fig. 38.—Xerophthalmia, an eye disease caused by a dietary deficiency of vitamin A. The cause of thousands of cases of blindness annually in India. (From Harris: *Vitamins in Theory and Practice*, 1935. Courtesy of the Cambridge University Press and the Macmillan Company.)

A more characteristic function of vitamin A is the maintenance of a normal condition of the eyes. A dietary deficiency of this substance produces an early disturbance of the eyes known as "night blindness," or nyctalopia (hemeralopia). An individual with night blindness cannot see well in dim light. This is due to a subnormal amount of visual purple in the retina. Further deprivation of vitamin A results in a more severely diseased condition of the eyes, known as xerophthalmia. In xerophthalmia the eyes become dry and a layer of horny tissue forms upon the cornea; later infection develops in the eyes, and blindness results if the diet is not corrected.

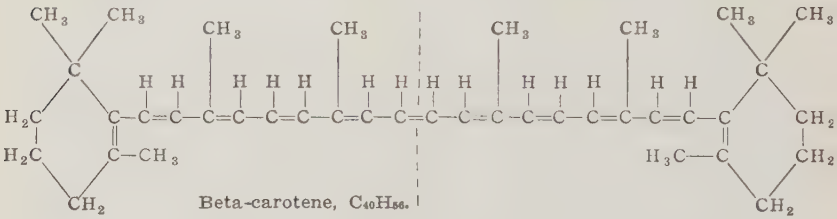
Nyctalopia has been observed for a long time, and it is more widespread throughout the world than might be suspected. Recent studies in the United States have shown an incidence of mild nyctalopia of 10 to 20 per cent in children of lower economic classes. The early physicians of Egypt and Greece recognized the condition and treated it by feeding liver, a practice which was an interesting forerunner of the modern usage of cod-liver oil as a source of vitamin A.

Xerophthalmia has been observed in Japan, in certain regions of Africa, in India, and in Denmark during World War I. It is found in people on a diet of rice, cereals, and non-leafy vegetables, with limited amounts of meats, milk, animal fats, and green and yellow vegetables. The disease is cured by giving foods containing vitamin A if treatment is instituted in time.

It is believed that vitamin A deficiency results in a lowered resistance to infection. When the vitamin A content of the diet is inadequate, the mucous membranes of the mouth, nose, throat, respiratory passages, and genitourinary tract become horny in character, a change called keratinization. Such changes in epithelial tissues lower the resistance of the structures involved and lead to infection in these tissues. It is claimed also that vitamin A does not improve resistance to infection. Such claims are based largely upon studies in which a dietary deficiency of vitamin A did not exist, and the experimental conditions were arranged to determine whether there is advantage in an excess of vitamin A in the diet. No advantage has been observed in experiments of this kind. It appears, therefore, that a distinction should be made between the effects upon resistance of a deficiency and an abundance of vitamin A in the diet. From the evidence, it seems justifiable to conclude that a dietary deficiency of vitamin A lowers resistance to infection; but, on the other hand, it is doubtful whether increased resistance to infection results from the introduction into the diet of an amount of this vitamin that is in excess of the quantity that prevents keratinization of the mucous membranes.

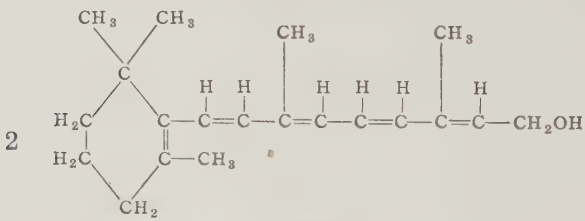
The origin of vitamin A is in plants. In certain fruits and vegetables there occurs a yellowish compound called carotene, of which there are several isomeric forms. It has been found that carotene, when present in the diet, has a protective influence similar to that of vitamin A. Experimental work has shown that carotene is converted into vitamin A in the liver by an enzyme called carotenase. Carotene is thus a provitamin, or a precursor of vitamin A. The animal obtains vitamin A either by ingesting foods containing this vitamin or by feeding upon carotene-containing foods which form vitamin A in passing through its liver.

The reaction by which one molecule of beta-carotene is split in the liver by the enzyme, carotenase, forming two molecules of vitamin A, is shown below:



Beta-carotene, $C_{40}H_{56}$.

↓ Carotenase



2 Vitamin A

Vitamin A is destroyed by prolonged heating in the presence of oxygen. The usual cooking and preserving processes used for foods do not impair appreciably their content of vitamin A or vitamin A precursors.

In summary, the functions of vitamin A may be stated briefly as follows: *Inclusion of vitamin A in the diet is necessary to promote growth of the young. A mild dietary*

deficiency of vitamin A results in early changes in the eyes, known as "night blindness" or nyctalopia. A more marked deprivation of this vitamin produces xerophthalmia, a disease of the eyes characterized by dryness, keratinization, and ulceration. It appears that a dietary deficiency of vitamin A lowers resistance to infection.

Fig. 39.—Above is a photograph of a pigeon suffering from polyneuritis. Below is the same pigeon a few hours after administration of vitamin B_1. (From Plimmer: Vitamins and the Choice of Food. Longmans Green & Co.)

Vitamin B_1 or Thiamine.—*A deficiency of vitamin B_1 in the diet results in loss of appetite, diminution in digestive secretions, lesions in the central nervous system, muscular atrophy, and finally paralysis. The disease resulting from this dietary deficiency in man is called beriberi, and the condition resulting from the same food deficiency in animals is called polyneuritis.*

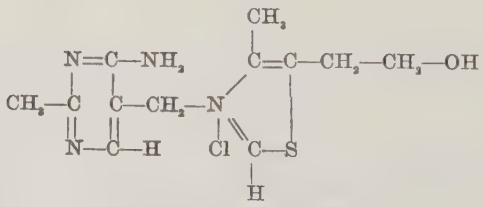
Beriberi is found in Japan, China, the Malay Peninsula, the Dutch East Indies, the Philippine Islands, and in regions of South America, Central America, and Africa. It is so widely prevalent in certain parts of the world that it constitutes a serious public health problem. Occasional cases are observed in the United States in individuals who have subsisted for a time upon a restricted diet.

Polyneuritis in animals is essentially similar to beriberi in man. The condition is readily produced by placing the animals upon a diet deficient in vitamin B_1. A great deal of our knowledge of vitamin B_1 has been obtained by a study of animals in which polyneuritis has been developed.

Beriberi is prevented, or successfully treated if the disease has already developed, by the administration of foods rich in vitamin B_1.

The first suggestion that beriberi is a disease caused by faulty diet was made by Eijkman, a Dutch physician, in 1897. Eijkman proved his contention by producing polyneuritis in chickens with a diet of polished rice and then curing the condition by feeding rice polishings to the fowls. Thus it was demonstrated that there is a nutritive principle in the hulls of rice which prevents polyneuritis. Subsequent work has shown that this principle is vitamin B_1.

Vitamin B_1 occurs in yeast, whole grain cereals, unpolished rice, meats, eggs, milk, and in vegetables and fruits in general. Yeast is the richest source of vitamin B_1. It is also found in large amounts in the pericarp of grains. The modern milling practice of removing the hulls from the grains, such as in the preparation of white flour or polished rice, removes a considerable part of the vitamin B_1.

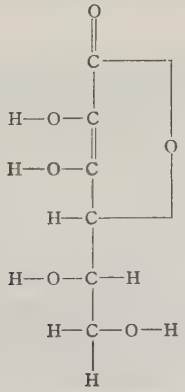


Vitamin B_1 or Thiamine

Vitamin B_1 is a water-soluble substance. When materials containing an abundance of this vitamin, such as yeast or rice polishings, are shaken with fuller's earth, an active adsorbing agent, at a certain acidity, the vitamin is adsorbed upon the fuller's earth. Later the vitamin is removed from the fuller's earth by the addition of alkali in appropriate amounts. In this way vitamin B_1 has been separated from natural sources in amounts that have permitted active investigation. Methods of purification have been developed, and it has been isolated in a pure crystalline state. Vitamin B_1 is now prepared synthetically for therapeutic use. It has been given the chemical name, "thiamine."

Vitamin B_1 is fairly stable chemically. Modern methods of cooking and preserving, except pressure cooking, do not affect the vitamin B_1 content of foods to an appreciable extent.

Vitamin C or Ascorbic Acid.—*Vitamin C must be present in the diet to prevent the condition known as scurvy. Scurvy is a disease that occurs in man, monkeys and guinea pigs.* In so far as is known, all other animals are able to synthesize their own vitamin C and are therefore not dependent upon a dietary source of this substance. Scurvy is a disease that



Vitamin C or Ascorbic acid

has long been known to be due to a lack of fresh fruits and vegetables in the diet. Sailors, explorers, invading armies,

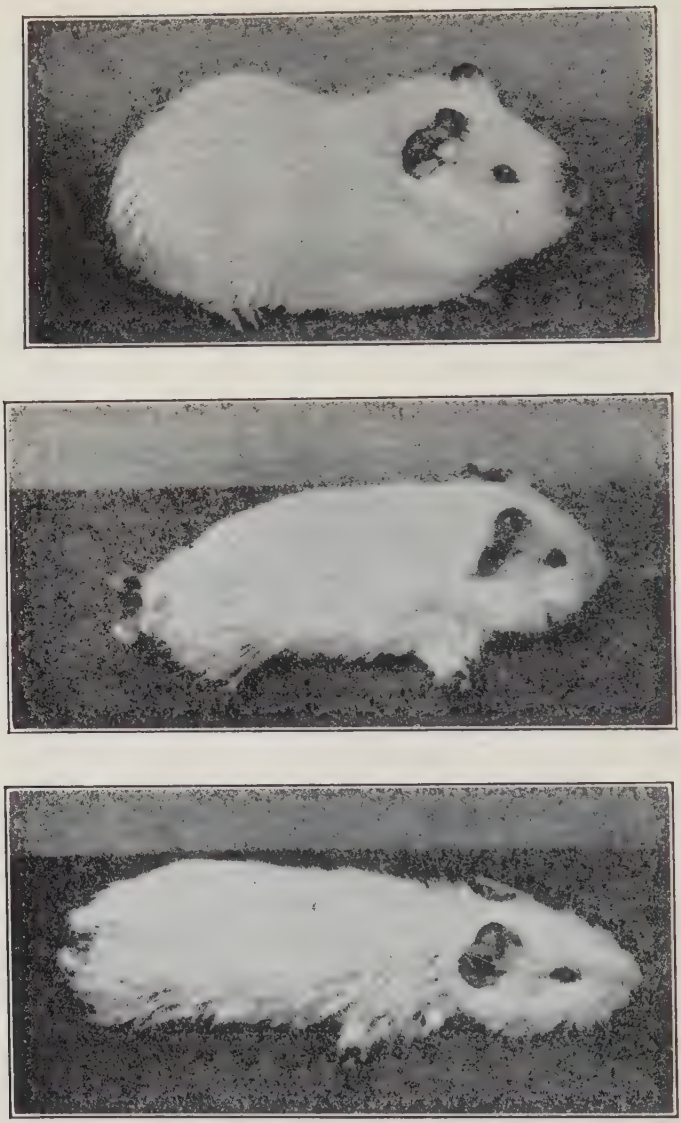


Fig. 40.—Guinea pigs with scurvy. *Above*, normal guinea pig. *Below*, guinea pigs with scurvy showing characteristic position. (From Rose: Foundations of Nutrition. Courtesy of the Macmillan Company.)

and all such groups of people who have had to exist for a time upon salted meats and preserved foods, have been victims of this disease in the past. As early as 1795, the British Navy adopted the practice of giving lime juice to all sailors in order to prevent the onset of scurvy. *The chief symptoms of scurvy are: swollen, bleeding gums; loosening and demineralization of the teeth; demineralization of the bones; hemorrhages into the mucous membranes, beneath the skin, and in the joints; and loss of weight.* This disease is cured by giving foods containing vitamin C.

Vitamin C is found in the greatest quantity in peppers, lemons, oranges, grapefruit, limes, cabbage, kale, broccoli, spinach, potatoes, turnips and tomatoes. Some vitamin C occurs in practically all fresh fruits and vegetables.

Vitamin C is destroyed by oxidation. When oxidizing agents are present, its destruction takes place slowly in an acid medium and very rapidly in the presence of alkalies. The canning industries protect the vitamin C of their products with considerable success by avoiding the introduction of alkali into their preparations and removing the oxygen by means of a vacuum pump before sealing the cans. Cooking decreases considerably the vitamin C content of foods. Losses of vitamin C in cooking arise from two factors: oxidation of the vitamin and passage of this highly soluble substance into the cooking water.

Vitamin C has been isolated in pure form from adrenal glands, lemon juice, and peppers, and it has also been made synthetically in the laboratory. Its chemistry is well known. It belongs to the class of monosaccharides, and probably originates in nature from the simple sugars. The chemical name given to this substance is "ascorbic acid."

Vitamin D.—*If an adequate amount of vitamin D is not present in the diet, the condition known as rickets results.* Rickets is essentially a disease of infancy and childhood. It is characterized by a failure in the deposition of calcium phosphate in the bones, which results in various bone malformations, such as bowlegs, knock knees, distorted spine, twisted pelvis, and enlargement of the osteochondral junctions of the bones. In addition to faulty

calcification of the bones, rachitic children show general symptoms, such as nervousness, irritability, loss of appetite, loss of weight, and anemia. Deficiency of this vitamin in the diet has probably contributed more than any other cause to faulty structural formations in the human race.

Vitamin D occurs in fish liver oils, egg yolk, butter, milk, liver, the fat of meats, oysters, and clams.

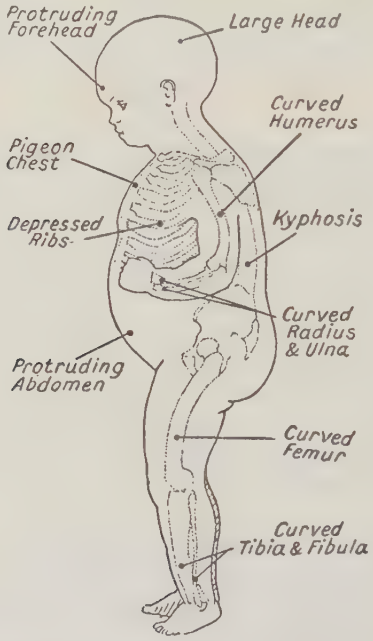
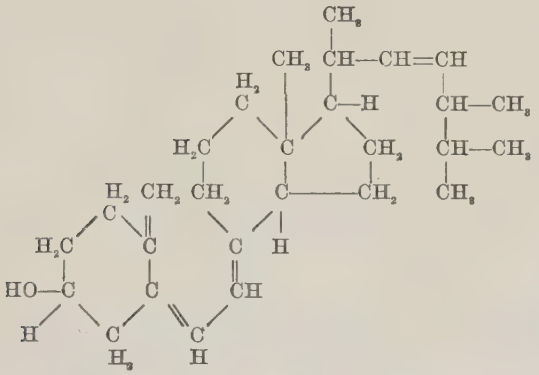


Fig. 41.—The symptoms of rickets. (From Harris: *Vitamins in Theory and Practice*, 1935. Courtesy of the Cambridge University Press and the Macmillan Company.)

Investigations of vitamin D have progressed so rapidly of late that we are in possession of considerable chemical knowledge of this vitamin. Of special interest is the fact that ergosterol, a complex alcohol, is the parent substance of one anti-rachitic compound. When ergosterol is exposed appropriately to ultraviolet light, several isomers of this substance are formed. One of these isomers, called "calciferol," has been obtained in a pure crystalline form and has been found to have an extremely high anti-rachitic potency. Because

calciferol has such a high potency, and since its preparation involves a process that is undoubtedly similar to the one in operation in the formation of naturally occurring vitamin D, namely, the photochemical action of ultraviolet light, it is believed that calciferol is the same substance as one form of vitamin D.



Calciferol, one form of vitamin D

Recent experimental work has shown that there is more than one anti-rachitic substance in Nature. Anti-rachitic activity has also been imparted to a number of substances by physical and chemical treatment. In 1937, Bills postulated the existence of eight different forms of vitamin D. All forms that have been observed or prepared are derivatives of either ergosterol or cholesterol, two well-known compounds in Nature, which belong to the class of sterols.

In 1919, Huldschinsky showed that infantile rickets could be cured by exposure of the rachitic child to the ultraviolet rays of a quartz-mercury vapor lamp. In 1921, Hess and Unger observed that a similar result is obtained by exposure of the child to direct sunlight. In 1924, Steenbock and Black found that certain foods, incapable of preventing rickets, may be made anti-rachitic by appropriate irradiation with ultraviolet light.

The imparting of anti-rachitic potency to certain foods by irradiation with ultraviolet light is due to the transformation of ergosterol or some derivative of cholesterol into anti-rachitic compounds. The development of anti-rachitic sub-

stances in the body by exposure to sunlight is the result of a similar photochemical effect upon ergosterol or a cholesterol derivative in the skin.

From the foregoing it is clear that the human race obtains its vitamin D both from food intake and from exposure of the body to direct sunlight.

The irradiation of foods to give them anti-rachitic potency has assumed some industrial importance. Many dairies are now enhancing the anti-rachitic quality of their milk by exposing it to ultraviolet light in appropriate apparatus for a few seconds. Milk is also being fortified in anti-rachitic potency by the addition of vitamin D concentrates.

Vitamin D is not affected by boiling at 100° C. for several hours, and it is fairly resistant to oxidation. The vitamin D content of foods is not impaired by the usual cooking and preserving processes.

Ergosterol is now prepared from plant sources and irradiated with ultraviolet light to produce a drug that is used for the prevention and treatment of rickets. Viosterol is the name adopted by the Council on Pharmacy and Chemistry of the American Medical Association for irradiated ergosterol.

Vitamin E.—*The dietary substance known as vitamin E has been shown to prevent sterility in animals.* The animal in which vitamin E has been demonstrated conclusively to be necessary for reproduction is the rat. Other animals in which it is claimed that sterility occurs as a result of vitamin E deficiency are cattle, chickens, and rabbits. Whether this dietary substance has an influence upon reproduction in human beings is under investigation; in general, the evidence from studies upon human subjects thus far has favored the idea that this vitamin is essential for reproduction, but the results are inadequate to make positive claims.

The effects of this vitamin deficiency upon the male and the female are different. Sterility in the male is caused by a pathological degeneration of the germinal cells of the testes which form spermatozoa. The inclusion in the diet of foods containing vitamin E prevents this reproductive failure; but after definite sterility has developed, the animal cannot be cured, as the pathological changes in the gonadal cells are permanent.

The female animal upon a diet deficient in vitamin E experiences a normal estrus cycle. Upon this dietary deficiency apparently normal ovulation takes place and pregnancy also occurs. During pregnancy pathological changes occur in the placenta and the developing embryo, and the fetus is resorbed. The degenerative changes are in the embryo rather than in the ovarian tissue or ova; consequently this form of sterility may be cured, as well as prevented, by the administration of foods containing vitamin E.

Vitamin E occurs in the embryo of grains, such as wheat and corn; in leafy vegetables as, for example, lettuce, spinach, water cress; and in small amounts in meats.

Vitamin E is a fat-soluble vitamin. It is not destroyed by heating to 250° C. It is stable to drying and to ordinary light. Rapid destruction of vitamin E is caused by oxidizing agents and by the "rancidity" substances in rancid fats. The vitamin E content of foods is not diminished by the usual cooking processes.

The Vitamin B-Complex.—In the early days of vitamin discoveries it was thought that the water-soluble substance in yeast, rice bran, whole wheat, etc., which promotes growth of animals and prevents polyneuritis, was a single compound, namely, vitamin B. Later it was shown that a second factor is present in the same water extract which would prevent pellagra. Hence, the factor preventing polyneuritis was called vitamin B_1 and the substance preventing pellagra was called vitamin B_2. The chemistry of these two substances was worked out and vitamin B_1 was given the name, thiamine, and vitamin B_2 was found to be nicotinic acid. In the course of investigations of the water-soluble extracts of materials containing vitamins B_1 and B_2 other nutritive factors were discovered. Since the source of these new factors was somewhat the same as that of the original vitamin B, it became the custom to designate the new factors by the letter B with a subscript (B_3, B_4, B_5, B_6) and this whole group of vitamins was considered as belonging to the "vitamin B-complex." Now there are in the vitamin B-complex nine members whose chemistry is well known, and several factors which appear to have physiological importance but whose true significance is unknown. We will discuss below those members of the

B-complex of which considerable is known concerning their chemistry and physiological significance.

Nicotinic Acid or Niacin—The Anti-Pellagra Vitamin.—The word pellagra means "skin seizure." One of the outstanding characteristics of pellagra is a skin lesion. In addi-

Fig. 42.—Pellagra in a child. Note the "butterfly wing" on the face and the rough hands. (From Stitt: *Diagnostics and Treatment of Tropical Disease.* Courtesy of P. Blakiston's Son & Co.)

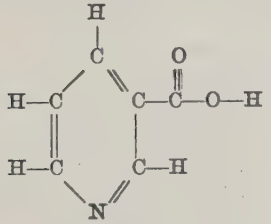
tion to dermatitis, pellagra is characterized by diarrhea, anemia, and lesions in the central nervous system producing mental confusion, dementia, and mania. As expressed by some writers, pellagra is characterized by the three D's, dermatitis, diarrhea, dementia. Pellagra is caused by a diet

that is deficient in nicotinic acid, or niacin. (The term niacin has been adopted as a substitute name for nicotinic acid.)

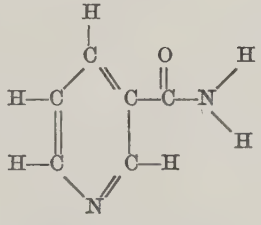
There is considerable pellagra in the United States, particularly in the southern states. This disease also occurs in southern Europe, particularly Italy, in Egypt, and in Africa.

The scientific solution of the problem of pellagra is due largely to the work of Goldberger and his associates. While working in state-controlled institutions in the South, this investigator came to the conclusion that pellagra is a disease due to a dietary deficiency. He proved his contention by a series of dramatic experiments in which he cured the pellagrins in certain institutions by placing them on an adequate diet. He also produced the disease in a group of volunteer human subjects (convicts from the Mississippi state penitentiary who were given their freedom for submitting to experimentation) by placing them on a diet like that eaten by pellagra victims and later cured those affected by giving them an adequate diet.

Many investigators have attempted to produce pellagra in animals by dietary means, and out of their efforts have come the prolific results leading to the discovery of other factors of the vitamin B complex. The lesion known as "black tongue" in dogs, first produced by Goldberger with an experimental diet, is the analogue of pellagra in man. In 1938, Elvehjem obtained an extract from liver highly active in curing black tongue, from which he separated nicotinic acid amide. He found that this substance and also synthetically prepared nicotinic acid would cure black tongue in dogs. In a few months clinical trials at several hospitals showed that *nicotinic acid is effective in curing human pellagra.*



Nicotinic acid



Nicotinic acid amine

The anti-pellagra vitamin is a water-soluble substance found in lean meats, eggs, vegetables, fruits, and most grains. It is deficient in corn, hence the widespread existence of pellagra amongst maize-eating people, whose intake of other foods is limited. This vitamin is quite stable chemically and is not destroyed by cooking.

Riboflavin.—As previously mentioned, from the efforts of investigators to learn the nutritive significance of the vitamin B-complex came the discovery of unknown nutritive substances of importance. One of these substances is riboflavin.

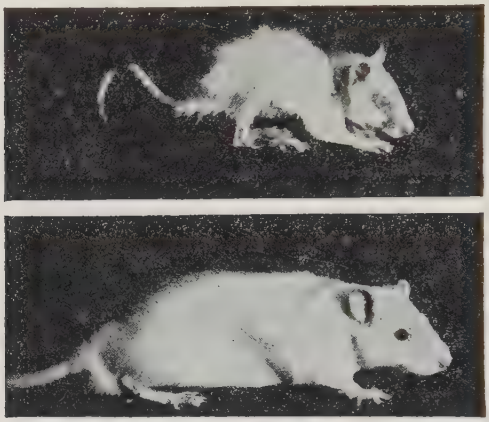


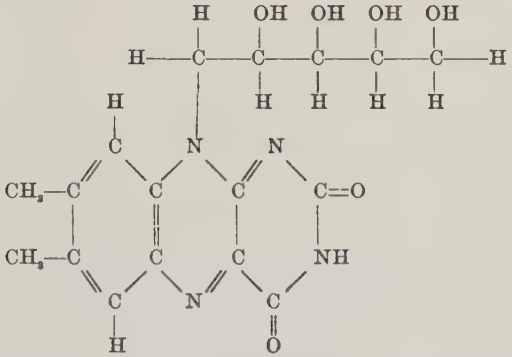
Fig. 43.—Photographs showing effects of riboflavin deficiency in the diet. *Above,* rat that received a riboflavin-deficient diet. *Below,* rat that received a riboflavin-deficient diet supplemented with 90 micrograms of riboflavin weekly; in this animal there was no evidence of alopecia or cataract. The animals were photographed on the seventy-fifth day of experiment, at which time they weighed 35 and 150 gm., respectively. (Day, Darby, and Langston: J. Nutrition **13**: 392, 1937. Courtesy of Dr. Paul L. Day and the Journal of Nutrition.)

Riboflavin is a water-soluble substance which occurs rather widely in foodstuffs. Rich sources of this vitamin are liver, kidney, eggs, yeast and milk.

Riboflavin is a constituent of certain enzymes that function in metabolism and respiration. It is essential that riboflavin be in the diet for the following reasons.

In the rat a riboflavin deficiency results in dermatitis, loss of hair, corneal vascularity (an abnormal extension of blood vessels into the cornea) and corneal opacity.

In man a dietary riboflavin deficiency produces eye disturbances: these are photophobia, lacrimation, conjunctivitis, corneal vascularity and corneal opacity. In the human subject ariboflavinosis also produces lesions in the angles of the mouth, on the lips and around the nose and eyes. Reddened macerated lesions form in the corners of the mouth which progress to transverse linear fissures, a condition called cheilosis. In addition to the cheilosis, a scaly, slightly greasy dermatitis appears around the nasolabial folds and in some cases around the eyes and ears. Ariboflavinosis is believed by some to be the most common deficiency disease in the United States.



Riboflavin

Riboflavin is a fairly stable substance chemically but is affected by light. It is not destroyed by cooking. Some of the effects of a riboflavin dietary deficiency are shown in Fig. 43.

Pyridoxine.—This substance is a constituent of the vitamin B-complex. Before its chemical structure was known it was called vitamin B_6.

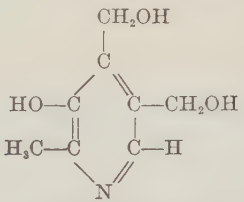
A dietary deficiency of pyridoxine produces a dermatitis in rats. This dermatitis is characterized by its location upon the paws, nose and ears of the rat. When first observed this condition was thought to be similar to the erythematous or pink disease of infants known as acrodynia, hence it has been called "rat acrodynia."

Another manifestation of pyridoxine deficiency is a convulsive state, of the nature of epileptiform fits. This condi-

tion has been produced experimentally in rats, pigs, dogs, and chicks.

In the dog, pyridoxine deficiency produces a microcytic, hypochromic anemia. This anemia appears in three to five months after the withdrawal of pyridoxine from the diet.

Pyridoxine is a water soluble vitamin. It was first isolated in 1938 and it is now prepared by chemical synthesis. The formula for this compound is given below.



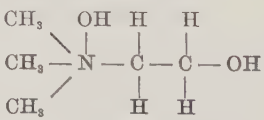
Pyridoxine

Pyridoxine activity in the rat seems to be related to the metabolism of the essential fatty acids. These fatty acids apparently are necessary in the diet to obtain maximum response from pyridoxine administration.

From the effects observed in animals it might be expected that pyridoxine has some function in man. Some interesting possibilities have been suggested by clinical trials but thus far the evidence is inadequate to make definite claims for a part played by this vitamin in human nutrition.

Rich dietary sources of pyridoxine are liver, yeast, rice bran, egg yolk, legumes, cereals, seeds and milk. It is a fairly stable substance chemically.

Choline.—Choline is effective in the animal body in relatively small amounts, hence it is classed as a vitamin. It is considered a member of the vitamin B-complex. The formula for choline is as follows:



Choline

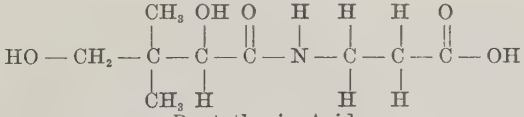
Choline is a constituent of lecithin, an important compound in nerve, brain and other body tissues. Its acetic acid

derivative, acetyl choline, is a stimulatory substance liberated at the parasympathetic nerve endings and at the endplates of the motor nerves of skeletal muscle when nerve action occurs.

Choline has a regulatory influence upon the deposition of fat in the liver. If the diet of an animal contains adequate choline, the fat content of the liver remains normal; but, in choline deficiency, there is a fatty infiltration of the liver, a condition called "fatty liver." The normal fat content of the liver of experimental animals, which ranges from 2 to 5 per cent, may increase to 20 to 25 per cent in a marked choline deficiency.

Besides opposing fatty infiltration of the liver, choline is effective in preventing a hemorrhagic degeneration of the kidneys in rats. Other pathologic results reported due to choline deficiency are a failure of lactation in rats and perosis (slipped tendon) in young turkeys.

Pantothenic Acid.—The biological importance of pantothenic acid was first suggested in 1930 by studies that indicated the existence of an unknown dietary factor which prevents a dermatitis in chicks. The chemical identity of this substance remained unknown for about 9 years and during this interval it was called the "chick anti-dermatitis factor," also the "filtrate factor" since a liver extract containing this substance could be shaken with fuller's earth and filtered and the active principle would pass through into the filtrate. Finally, in 1939, it was shown that the "chick anti-dermatitis factor" is identical to pantothenic acid, the formula of which is given below.



Pantothenic Acid

An interesting nutritional effect of pantothenic acid is its prevention of the graying of hair in fur-bearing animals. Upon a pantothenic acid deficient diet, black rats will turn gray, and dogs and silver foxes show a loss of dark pigment from the hair. The addition of pantothenic acid to the de-

ficient diet will restore the natural pigment to the hair; and upon a diet adequate in pantothenic acid, depigmentation of hair does not occur. The absence of pigment from hair is called "achromotrichia." The prevention of achromotrichia in certain animals by pantothenic acid has been well established.

In addition to the prevention of dermatitis in chicks and achromotrichia in fur-bearing animals, pantothenic acid has other effects in animals. Absence of this vitamin from the diet causes retardation of growth in chicks, rats, and dogs. Other pathologic effects reported as being due to this deficiency are degenerative changes in the adrenal cortex, kidneys, heart and muscles in rats; fatty liver, hemorrhagic kidneys and gastrointestinal pathology in the dog; and poor feathering, fatty liver and nerve tissue degeneration in chicks.

Thus far a distinct relationship of pantothenic acid to human nutrition has not been found. It would seem to have some value in human nutrition in view of its importance to animals. Studies of its ability to restore pigment to gray hair in human subjects have not yielded positive results. Further work of a carefully controlled scientific nature will have to be done to show whether or not this vitamin will prevent depigmentation of hair, or restore pigment to gray hair, in human subjects.

Good natural sources of pantothenic acid are liver, meats, cereals and milk. It is now prepared by chemical synthesis.

Biotin.—Biotin is one of the more recently discovered members of the vitamin B complex. It is essential in the diet of animals and man. The most general symptom of biotin deficiency is a dermatitis. In rats, besides causing a dermatitis, biotin deficiency results in retarded growth, fatty liver and gangrene of the tail. In human subjects, biotin deficiency produces such symptoms as scaly dermatitis, grayish pallor of the skin, anorrhexia, nausea, muscle pains, depression and lassitude. These pathologic effects disappear promptly when the subject receives an adequate amount of biotin.

The discovery of biotin came in a roundabout way. For a number of years it was known that a characteristic dermatitis could be produced in rats when the latter were fed a diet containing a rather high amount of raw egg white. This effect could be prevented by feeding liver, kidney, yeast and certain other foods. The substance in the foods which prevented the effects of raw egg white was called vitamin H,

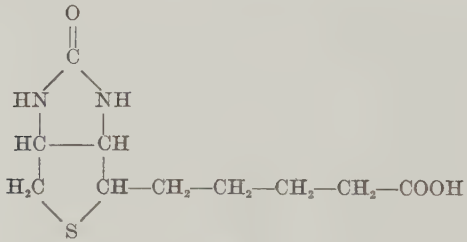
Fig. 44.—The rat on the left, whose hair was originally black, shows graying of the hair as the result of a diet deficient in the anti-gray hair factor. Its litter mate on the right received a normal diet. (Reproduced from *Therapeutic Notes,* courtesy of Parke, Davis & Co.)

also the "anti-egg-white injury factor." In 1940, it was shown that biotin and vitamin H are the same substance. The part played by the raw egg white was as follows: Raw egg white contains a protein, called "avidin," which combines with biotin and makes it inactive. The feeding of raw egg white resulted in a loss of biotin to the animal because this compound became bound to avidin in the intestinal

tract and was excreted in the feces. Heated egg white has no biotin-binding effect because heating inactivates avidin.

Rich sources of biotin are liver, kidney, yeast and egg yolk. Experimental work has indicated that biotin is synthesized by bacteria in the intestinal tract of animals. It is probable that there is sufficient biotin synthesis by bacteria in the intestine of the rat to meet the biotin needs of this animal but the chick does not receive enough biotin in this way to meet its requirement. The biotin deficiency syndrome has been produced experimentally in human subjects by feeding a diet containing one-third of the calories in the form of raw egg white.

Synthetically prepared biotin is now available for use. The structural formula for this vitamin is given below.



Biotin

Folic Acid.—Folic acid has an anti-anemia effect in chickens and rats and it also stimulates the growth of certain bacteria. The biological importance of this vitamin was first suggested in 1941. Its name is derived from the Latin word, *folium,* meaning a leaf. It was given this name because it occurs in unusual amounts in green leaves of many kinds, including grass. It has a widespread occurrence in the biological kingdom. In addition to green leaves, liver, kidney, yeast and mushrooms are good sources. It appears that certain bacteria, notably the coliform organisms of the intestinal tract, have the power to synthesize this compound.

Recent experimental work has indicated that this vitamin is essential for the formation of the white cells as well as the red cells of the blood. Rats were placed upon a synthetic diet containing all required nutrients except folic

acid. To this diet was added one per cent of sulfaguanidine. After a period upon this diet ranging from four to fifteen weeks the rats developed a leukopenia and an anemia, apparently because the sulfone drug sterilized the intestine and prevented the synthesis of folic acid by bacteria. When crystalline folic acid was given to these rats, the red and white blood cell counts were restored to normal. Thus it was shown that folic acid is effective in preventing leukopenia, as well as anemia, in the rat.

Vitamin K.—While working upon the metabolism of sterols at the University of Copenhagen, Dam, in 1929, observed a hemorrhagic condition in chickens upon a certain type of diet. The chicks, when placed upon the diet used, developed subcutaneous and deep intramuscular hemorrhages. This hemorrhagic condition was soon found not to be related to scurvy, as the administration of vitamin C did not improve the lesion. Subsequent work by Dam showed that a vitamin-like substance in the diet prevents this condition. Dam named this factor vitamin K.

Vitamin K is a fat-soluble, thermostable, dietary principle. It is synthesized by plants, its occurrence being most abundant in green plants. Alfalfa, kale, spinach, cabbage, and grass contain an abundance of vitamin K, while potatoes, mushrooms, tomatoes—foodstuffs with little or no chlorophyll—have a low vitamin K content. This vitamin has recently been obtained in a pure crystalline form.

The effect of vitamin K is to stimulate the production of the prothrombin of the blood by the liver. When there is a deficiency of this vitamin, the blood has a slow coagulation time because of its reduced content of prothrombin, one of the factors entering into the formation of the blood clot. There must be bile in the intestinal tract to bring about the absorption of vitamin K.

Vitamin K has been used clinically with success in the treatment of the hemorrhagic condition sometimes associated with jaundice. In obstructive jaundice bile is not present in the alimentary tract, hence vitamin K is not absorbed and supplied to the liver for the production of prothrombin. There is also liver damage associated with the jaundice. Therefore,

the prothrombin content of the blood is rapidly reduced. An effective aid in the treatment of this condition is the administration by mouth of vitamin K concentrate, together with bile salts, to promote the absorption of the vitamin, also the intramuscular injection of vitamin K preparations dissolved in oil.

Questions for Study

1. Give the origin of the name "vitamin."
2. Discuss the earliest significant experiments leading to the discovery of vitamins.
3. What is nyctalopia? Xerophthalmia?
4. Summarize the functions of vitamin A.
5. What conditions are prevented by vitamin B_1?
6. What condition does vitamin C prevent? How is the vitamin C of canned foods preserved by modern methods of canning?
7. What is vitamin C chemically?
8. What condition is prevented by the presence of vitamin D in the diet?
9. What chemical substance may be naturally occurring vitamin D?
10. What is the relationship of ultraviolet light to the prevention of rickets?
11. Name some foods that are fortified in vitamin D?
12. What is the effect of a dietary deficiency of vitamin E upon the male and the female?
13. Describe the lesion known as pellagra.
14. What dietary substance will prevent pellagra?
15. What are the effects of a dietary deficiency of riboflavin?
16. What are the effects of a dietary deficiency of pyridoxine in the rat? In the dog?
17. Of what important biological compounds is choline a constituent?
18. What pathologic conditions arise in animals as a result of choline deficiency?
19. What are the principal pathologic effects of a dietary deficiency of pantothenic acid in chicks? In rats? In dogs and silver foxes?
20. What are the effects of a dietary deficiency of biotin in the rat? In man?
21. What is avidin and how may it bring about a dietary deficiency of biotin?
22. What are the effects of a dietary deficiency of folic acid? How were these effects demonstrated in the rat?
23. What is the physiologic effect of vitamin K? What substance must be present in the alimentary tract to bring about the absorption of vitamin K?
24. What clinical applications of vitamin K have been made?

PLATE III.—THE TYPICAL HEMORRHAGIC DISORDER CHARACTERIZED BY SUBCUTANEOUS GIZZARD AND INTRAMUSCULAR HEMORRHAGE ANEMIA AND PROLONGED COAGULATION TIME OF THE BLOOD OF THE CHICK DUE TO VITAMIN K DEFICIENCY. (Courtesy of Eli Lilly and Co.)

CHAPTER XXXVII

HORMONES

Hormones are internal secretions. They are elaborated by glands that discharge these highly important physiological substances directly into the circulating fluids of the body. In contradistinction to an external secretion, an internal secretion is not discharged through a duct into the lumen of an organ, but is secreted into the blood and lymph and conveyed by the latter to its site of activity. The hormones have a remarkable influence upon the growth, size, appearance, functioning, and general metabolism of the body. They are effective in very small quantities, hence they are believed to act as catalysts. These substances are called hormones, a name which comes from a Greek word meaning "to arouse to activity," because of their stimulating influence upon the functioning of the body.

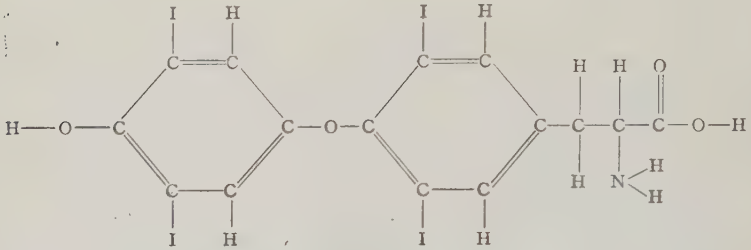
The glands producing internal secretions were once known as the ductless glands because of the absence from their structure of secretory ducts. They are now called the endocrine organs. The more important endocrine organs are the thyroid and the parathyroid glands, the pancreas, the adrenal glands, the pituitary gland, the ovaries, the testes, and the thymus. The biochemical significance of the secretions of each of these will now be discussed.

Thyroxin.—Thyroxin is a secretion produced by the thyroid gland. The thyroid gland is a bi-lobed, highly vascular organ, situated in the neck in front of the larynx and trachea. In man the normal thyroid weighs about 20 to 25 grams. It is larger per unit of body weight in the female than in the male.

The chemistry of thyroxin is well known. It has been isolated in the pure form from the thyroid glands of animals and has also been prepared synthetically in the laboratory.

Thyroxin has a very profound influence upon body functions. It has a stimulating effect upon growth; it is con-

cerned in the metabolism of the skin, the latter becoming thick and dry when the hormone is deficient; and it has a marked regulatory influence upon the rate of oxidations in the body. It is extremely potent; one milligram of thyroxin will increase the oxidations that take place in the human body 3 per cent.



Thyroxin

If the thyroid gland fails to develop properly in fetal life or in childhood, an individual stunted both physically and mentally is the result. Such an individual is called a cretin, and the condition is known as *cretinism.* A cretin is a dwarfed, pot-bellied, ugly individual, with coarse hair, coarse, dry skin, subnormal basal metabolism, and low mentality. Should atrophy of the thyroid gland occur during adult life, symptoms somewhat similar to those found in cretinism, with the exception of stunted growth, will result. One of these symptoms is the development of a thick, coarse, dry skin, a condition called *myxedema;* other symptoms are a reduced basal metabolism, a lowered pulse rate, a tendency to subnormal body temperature, and physical and mental sluggishness. All of these abnormalities of structure and function are due to a deficient production of thyroxin by the thyroid gland, a condition known as hypothyroidism.

A cretin may be made to grow normally if fed preparations containing thyroxin before adult age is reached; and other symptoms of cretinism, such as coarse hair and skin, subnormal basal metabolism, and dwarfed intellect, may be improved or even made to disappear entirely if thyroxin treatment is instituted. Likewise the symptoms of hypo-

thyroidism in the adult, such as myxedema, subnormal metabolism and physical incapacity will disappear when the subject is given a properly outlined treatment with thyroid extract.

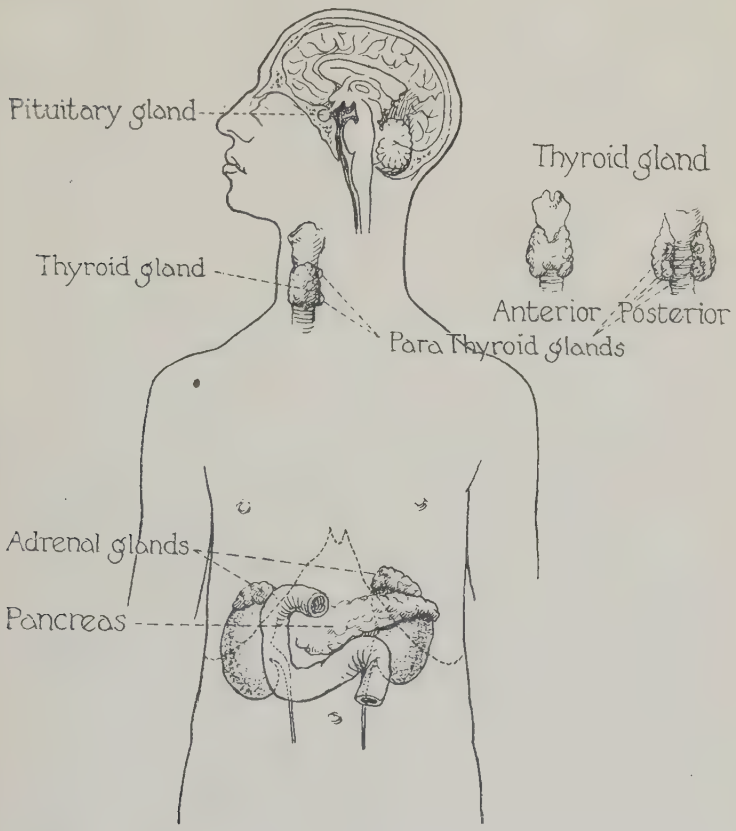


Fig. 45.—Diagram showing location of glands of internal secretions.

Another form of thyroid disease is the condition known as *simple goiter*. This is a hyperplasia, or increase in the cellular elements, of the thyroid gland. There is also a marked increase in colloid material in the gland, hence the name colloid goiter is sometimes used. In this type of thyroid disease there is more or less swelling of the neck in the region of the thyroid as a result of the hyperplasia of the gland.

Simple goiter is due to a deficiency of iodine in the food and drinking water. It is endemic in regions in which there are very small amounts of iodine compounds in the soil and subsoil, and consequently a low iodine content in the drinking water and in the vegetables grown in these regions. The districts of highest incidence of simple goiter are the Himalaya mountain region of Asia, the region of the Alps in Europe, the Andes plateau of South America, the region about the Great Lakes and St. Lawrence River, and the Cascade mountain region of Washington, Oregon, and British Columbia, in North America. This disease is now being successfully prevented by the introduction of iodine compounds into the diet, or by the ingestion of sodium iodide or other iodine salts periodically. The best results obtained by iodine therapy are naturally prophylactic or preventive. When once developed, the management of simple goiter becomes more difficult. Some success is obtained by alternating courses of administration by mouth of desiccated thyroid gland and small amounts of iodine. Care must be observed, however, to avoid overdosage of iodine.

The thyroid may also manifest increased as well as subnormal activities. The condition in which there is overactivity of the thyroid gland, producing excessive amounts of thyroxin, is known as *hyperthyroidism*. It has been called Graves' disease and Basedow's disease. Its principal symptoms are an increased basal metabolic rate, a rapid and irregular heart rate, exophthalmos or bulging of the eyes, restlessness, hyperexcitability, and loss of weight. In this condition the individual is very much speeded up biologically, his vital activities taking place much too fast, in direct contrast with the hypothyroid condition in which the individual is dull and sluggish, both physically and mentally, with greatly lowered vital activities. The treatment of hyperthyroidism is the removal of parts of the thyroid gland by surgery, or exposure of the region of the gland to x-rays.

Secretion of the Parathyroid Glands.—The parathyroid glands are small, bean-shaped structures, which in man are about 3 to 15 mm. long and 2 to 3 mm. broad. They are

situated in the neck on the posterior surface of the thyroid gland. There are usually four of these glands in man, two on each lobe of the thyroid.

The parathyroid glands are concerned in the regulation of calcium metabolism. The normal calcium content of the blood under fasting conditions is 9 to 11 mg. per 100 c.c. of serum. The particular action of the secretion of the parathyroid glands is the maintenance of this normal circulating level of calcium in the blood. If the parathyroid glands are removed from a dog, the animal's blood calcium content is lowered; it develops tetany and dies in spasms in a few days unless treatment is introduced. Tetany produced in this way is relieved by injecting an extract of the parathyroid glands, which raises the level of the blood calcium; also by injecting a soluble calcium salt, which has the same effect as injecting parathyroid extract, namely, increasing the blood calcium content. A similar influence is exerted upon a normal animal by an extract of the parathyroid glands: If parathyroid extract is injected into a normal animal, the blood calcium is increased for a time to a level higher than normal. Experiments like the above show that the secretion of the parathyroid glands is definitely related to the mobilization of calcium in the blood. Whether the blood calcium is low or normal, *the injection of parathyroid extract brings about an increase in the circulating level of calcium. This mobilization of calcium in the blood is apparently brought about by a withdrawal of calcium from its storage deposits in the bones.*

Parathyroid extract has been found of value clinically in the treatment of calcium metabolism disturbances.

Insulin.—Insulin is a secretion of the islands of Langerhans of the pancreas. It is a hormone which has an important part in the regulation of carbohydrate metabolism. The normal concentration of sugar in the blood under fasting conditions is from 65 to 100 mg. per 100 c.c. The influence of insulin is to maintain this circulating level of blood sugar. Insulin accomplishes this function by aiding in the storage

of glucose as glycogen in the muscles and liver and by facilitating the oxidation of glucose. Following a meal containing carbohydrates, there is an elevation of the blood sugar to a concentration of perhaps 120 to 160 mg. per 100 c.c. of blood, a condition called hyperglycemia. This concentration of sugar is soon reduced to the normal level partly by the conversion of glucose to glycogen and the

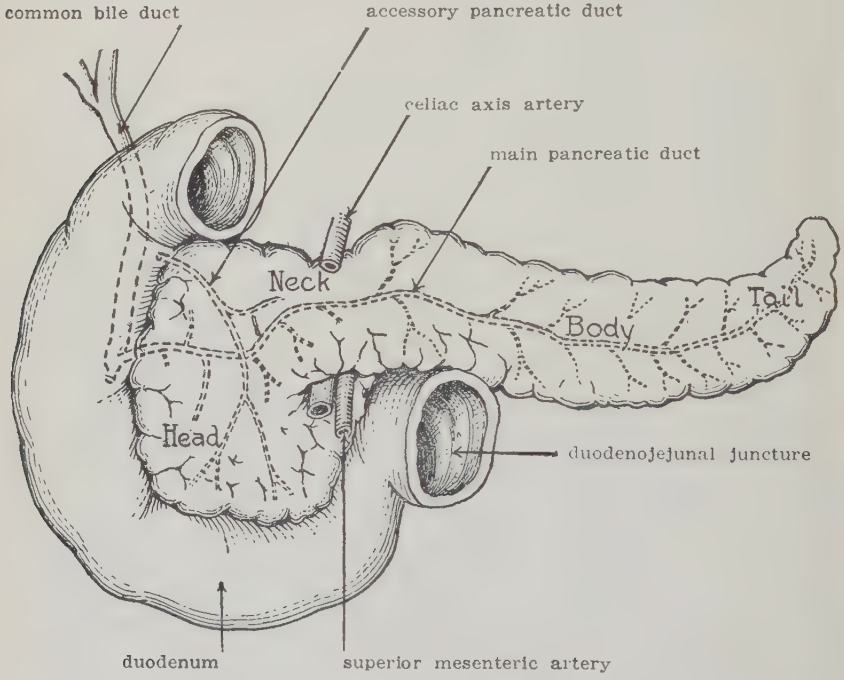


Fig. 46.—Diagram of the pancreas and duodenum. (From Pitzman: *Fundamentals of Human Anatomy.* The C. V. Mosby Co.)

storage of the latter, and partly by the oxidation of glucose to carbon dioxide and water. Insulin aids in the storage process, as shown by the fact that there is little or no storage of glycogen in a depancreatized animal which cannot produce insulin. Insulin also facilitates the oxidation of glucose, as shown by chemical tests (respiratory quotient studies) which reveal an increased oxidation of sugar following the injection of insulin.

Continuous hyperglycemia, or elevation of the blood sugar above normal, is a pathological condition. If under fasting conditions the circulating level of the blood sugar is found to be in excess of 130 mg. per 100 c.c., there is some bodily dysfunction, which is nearly always a deficient production of insulin by the pancreas. *The disease in which there is pancreatic dysfunction resulting in insulin deficiency is known as diabetes mellitus. In this disease there is a failure to store and to burn glucose.* It is characterized by an increased blood sugar and by glucosuria. As a result of the failure to burn glucose, there is excess ketone body formation with marked ketonemia and ketonuria. The excretion of ketone bodies, two of which are acids, depletes the body's bases and causes an acidosis.

Insulin is prepared for clinical use by extraction of the macerated pancreases of animals (hogs, cattle, sheep) with acid alcohol, followed by a series of chemical steps of purification. The purified product is dissolved in dilute hydrochloric acid, and its potency is determined by its action upon rabbits. It is issued for use in sterile solutions of such concentrations that 1 c.c. contains 20, 40, 80, or 100 units, a unit of insulin being one-third of the amount that will lower the blood sugar of a fasting 2-kilogram rabbit to the level at which convulsions occur within a period of five hours following its injection. It is generally considered that one unit of insulin will bring about the combustion of approximately 2 grams of carbohydrate in the human body.

Insulin has been obtained in a pure crystalline form. It has been found to be a protein with a molecular weight of about 35,000. It is administered by subcutaneous injection of its solution, and it is ineffective when given by mouth because, being a protein, it is digested in passing through the alimentary tract by proteolytic enzymes. The effectiveness of insulin is reduced by the presence of infection in the body.

It is important to realize that the injection of insulin will lower the concentration of blood sugar whether the latter is high or low. If insulin is given to a diabetic patient with a high blood sugar, this patient's blood sugar will be re-

duced; and if given to an individual with a normal blood sugar, there will be a lowering of the blood sugar to a level below normal. When the blood sugar becomes lower than normal, the condition is called hypoglycemia. This sometimes occurs from an overdosage of insulin. Hypoglycemia is an undesirable and often dangerous condition. In hypoglycemia of moderate degree, such as when the blood sugar is around 50 mg. per 100 c.c., the patient manifests such symptoms as sweating, nervousness, tremor of lips and hands, blurring of vision, and dizziness. In more advanced hypoglycemia, as when the blood sugar is 25 to 35 mg. per 100 c.c., the patient becomes unconscious. Hypoglycemia and its attendant symptoms may be promptly dismissed by the administration of sugar, either by mouth or intravenously, the intravenous method giving the more rapid response.

Secretions of the Pituitary Gland.—The pituitary body, or hypophysis cerebri, is a small gland weighing about 0.6 gram in man, situated at the base of the brain in a groove in the sphenoid bone. It consists of three parts, an anterior lobe, a posterior lobe, and a middle lobe or pars intermedia. These three lobes are attached by a stalk, called the infundibulum, to the floor of the third ventricle of the brain, the whole structure being encased in the dura mater and pia mater, the membranes which invest the brain. The three lobes differ from each other as to embryologic origin, structure, and function.

The pituitary gland may be considered the master gland of the body. Its secretions have not only very important direct physiological effects, but also a controlling influence upon other endocrine organs. There are at least six hormones secreted by the anterior lobe of the pituitary gland, and two substances elaborated by the posterior lobe of this gland.

Of the anterior lobe secretions a very important one is a hormone that influences growth. If a deficiency of this secretion occurs before maturity, there results an incomplete growth which in extreme cases amounts to dwarfism. An excessive secretion of the hormone of this lobe produces

abnormal growth. If the hypersecretion occurs before adult life, gigantism results. In gigantism there is unusual growth of the long bones of the body, producing a subject of gigantic proportions (see Fig. 47). If the increased secretion

Fig. 47.—Giants and dwarfs owe their abnormal stature to the overactivity or underactivity of the pituitary gland. (Courtesy Press Association, Inc., New York.)

occurs during adult life, the principal manifestations are abnormal growth of the hands and feet and of the bones of the face, a condition known as acromegaly.

The anterior lobe produces a gonadotropic hormone; that is, a substance which has a stimulating influence upon the

development of the genital organs. Surgical removal of the anterior pituitary gland is followed by atrophy of the testes, seminal vesicles, and prostate gland if the animal is a male; and atrophy of the ovaries, uterus, and Fallopian tubes if the animal is a female. The pituitary forms a secretion that promotes the development of normal size and normal function of the testes in the male, and of the ovaries in the female. The testes form secretions which stimulate the growth and function of the other reproductive organs of the male; and the ovaries produce secretions which have a similar effect in the female. The anterior pituitary gland thus influences by direct and indirect means the normal development and functioning of the reproductive organs of the male and female sexes, a relationship which will be discussed more fully later in the section on Sex Hormones.

Removal of the anterior pituitary gland brings about an atrophy of the thyroid gland, and results in a lowered basal metabolism. The administration of proper amounts of anterior pituitary extract to an animal whose pituitary has been removed will restore normal size and function to the thyroid gland. Administration of anterior pituitary extract to normal animals produces enlargement and hyperplasia of the thyroid gland. The substance having these physiological effects is called the thyrotropic principle of the pituitary gland.

The adrenal glands atrophy when the anterior pituitary gland is removed from an animal. Administration of anterior pituitary extract restores the glands of such an animal to normal. Thus it has been shown that the pituitary secretes a principle which aids in maintaining normal structure and function of the adrenal glands. This principle is called the adrenotropic hormone.

It has been found that the anterior pituitary gland secretes a hormone that stimulates the production of milk in the mammary glands of the lactating female. This substance is known as the lactogenic hormone, and it is called "prolactin."

The anterior pituitary gland also secretes hormones which influence carbohydrate metabolism. One of these principles

has an effect antagonistic to insulin. Another substance appears to have a degenerative effect upon the beta cells of the Islands of Langerhans when administered to animals in excess quantities; such administrations produce hyperglycemia, glucosuria and ketonuria. A permanently diabetic condition has been produced in dogs by daily injection of anterior pituitary extract for several weeks.

To summarize, it may be said that *the anterior pituitary gland secretes growth-promoting, gonadotropic, thyrotropic, adrenotropic, lactogenic, and diabetogenic hormones.*

The secretions of the posterior lobe of the pituitary gland have at least three physiological effects. Posterior pituitary extract will raise the blood pressure of animals under certain experimental conditions, such as anesthesia, but it does not affect the blood pressure of man. Posterior pituitary extract has a stimulating action upon smooth muscle; this action is characteristically effective upon uterine muscle, causing contractions of the uterus, a physiological response which is called the oxytocic effect. Posterior pituitary extract also has an anti-diuretic action; that is, it diminishes the flow of urine. Disease or injury of the posterior pituitary brings about severe polyuria, with marked thirst, a condition known as *diabetes insipidus.* This condition is relieved by the administration of posterior pituitary extract.

The principal clinical uses of posterior pituitary extract are in the treatment of diabetes insipidus and in obstetrics. It is a practice among obstetricians to administer pituitary extract immediately after the birth of the baby in order to control bleeding and to hasten the expulsion of the placenta. Obstetricians are very conservative in the use of pituitrin to induce labor, because of the danger of rupture of the uterus or of injury to the baby. Modern usage is limiting the application of this substance in obstetrics to the control of postpartum hemorrhage and the facilitation of the removal of the placenta.

Secretions of the Adrenal Glands.—The adrenal glands are small, highly vascular organs, one being located just above

the upper pole of each kidney. In man the weight of one gland is about 4 grams. Each adrenal body consists of two parts, the cortex and the medulla. The cortex is the outer portion of the gland, and the medulla is the central part. Each of these parts is distinct structurally and functionally, and each produces an internal secretion of utmost importance.

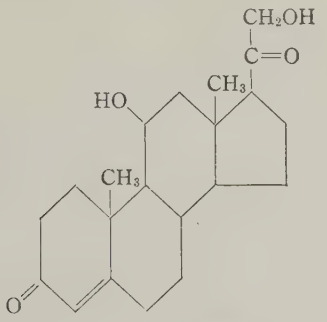
If the adrenal glands are removed from an animal, the animal will not live. Death is due to the absence of a hormone, or hormones, secreted by the cortex. Pathology of the adrenal cortex in man brings on the condition known as *Addison's disease*. In Addison's disease there is a marked bronze coloration of the skin, profound weakness, prostration, loss of appetite, nausea, and vomiting.

Chemical analyses of the blood of patients with Addison's disease have revealed a decrease in the blood sugar and the sodium, chloride, and bicarbonate ions, and an increase in the nonprotein nitrogen of the blood. Blood analyses of animals from which the adrenal glands have been removed show similar changes in blood composition. Following adrenalectomy, animals become dehydrated, their blood volume decreases, and there is a fall in blood pressure. Chemical studies of the urine of adrenalectomized animals show an increased excretion of sodium chloride and water following the removal of the glands.

The administration of sodium chloride improves the condition of patients suffering with Addison's disease. Sodium chloride administration also alleviates the moribund state of adrenalectomized animals and prolongs their survival period.

From the evidence related above it appears that the function of the substance, or substances, secreted by the adrenal cortex is to regulate the metabolism of the sodium ion and that this is accomplished by controlling the renal excretion of this ion. From the fact that there is a low blood sugar and a lowered content of muscle and liver glycogen in adrenal insufficiency it follows that the adrenal cortex exerts an effect upon carbohydrate metabolism. This effect is a stimulation of the conversion of sugar-forming amino acids into glucose, a metabolic process called gluconeogenesis.

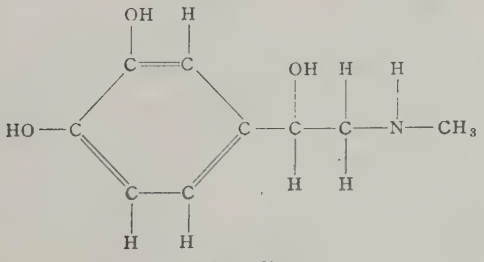
Extracts of the cortex of the adrenal glands of animals have been prepared by a number of investigators. These extracts have the power to keep adrenalectomized animals alive and in good condition for an indefinite time. Potent preparations from the adrenal cortex have also been obtained in a pure crystalline state. At the time of this writing the evidence indicates that there are at least six substances secreted by the adrenal cortex, which participate in the functions of this gland. The formula for one of these substances, corticosterone, is given below.



Corticosterone

Extracts prepared from the adrenal cortex of animals have been used with success in the medical and surgical treatment of patients with Addison's disease.

The chemistry and physiological action of the secretion of the adrenal medulla are well known. It has been obtained in a pure form from the adrenal glands of animals and has also been prepared synthetically in the laboratory. This secretion is known as adrenalin, suprarenin, and epinephrine,



Adrenalin

the last mentioned name being the one officially adopted by the United States Pharmacopeia.

Adrenalin has either a stimulating or an inhibiting effect upon all structures innervated by the sympathetic nervous system. Of these effects the most important are the acceleration of the heartbeat, the raising of blood pressure due principally to a constriction of the blood vessels, the relaxation of the bronchial muscles, contraction of the muscles of the skin that raise the hair, and the dilatation of the pupil of the eye. It also facilitates the conversion of glycogen to glucose in the liver, increasing the level of blood sugar.

The principal uses of adrenalin in medicine are: (1) as an emergency aid in heart failure, since it has a marked cardiac-stimulating power; (2) in alleviating the spasm of bronchial asthma, as it relaxes the bronchial muscles; and (3) in arresting hemorrhage where it can be applied locally, especially in local operations, by virtue of its powerful constricting influence upon the blood vessels.

Thymus.—In man the thymus is situated partly in the lower portion of the neck and partly in the upper thorax. Its size is related to the age of the individual. At birth the thymus weighs about 15 grams, and at puberty it weighs around 35 grams; after puberty it undergoes involutionary changes and gradually decreases in size, weighing approximately 25 grams at 25 years of age and less than 15 grams at the age of 60.

Surgical removal of the thymus gland does not result in the death of the animal, showing that the gland is not essential to maintain life.

Recently a study of the effects of an extract of the thymus gland has given significant results. Young rats receiving daily intraperitoneal injections of an aqueous extract of the thymus glands of calves have shown strikingly rapid rates of growth up to the time of puberty. These changes were not apparent in the first and second generations, but beginning with the third generation there was a marked increase in the rate of growth of the newborn rats and a striking acceleration of the onset of maturity changes, such as erup-

tion of teeth, opening of the eyes, and growth of the hair. The animals do not become giant rats, however, the effects of administration of the thymus extract being to produce precocity in growth and rapid maturity changes.

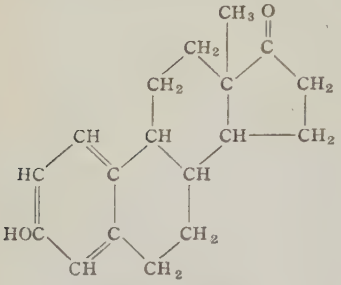
Chemical analyses of the blood of the young rats, which grew so rapidly under treatment with thymus injections, revealed definite increases in the circulating level of the serum calcium and inorganic phosphorus. Since calcium and phosphorus are essential for bone formation, these changes in the blood seem definitely related to the rapid skeletal development of the rats receiving thymus injections.

Aside from the results described above there has been little experimental work that has shed light upon the physiological relations of the thymus gland. From the results discussed, it seems clear that the thymus secretes a hormone which influences the rate of growth and accelerates the onset of maturity.

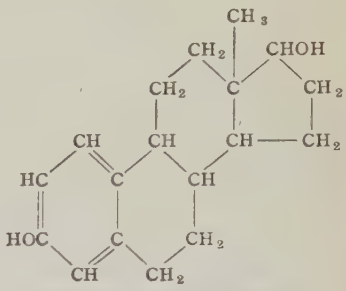
Female Sex Hormones.—Our consideration of the female sex hormones will include the substances, estrone (also called theelin), estradiol (or dihydrotheelin), estriol (or theelol), and progesterone, which are formed in the ovaries, and the gonad-stimulating principles of the anterior pituitary gland. The chemistry of the pituitary principles is unknown. The chemical nature of the other substances mentioned is now well known.

Estrone was first isolated in pure form from the urine of pregnant women. Its preparation was reported in 1929. In 1930, another female sex principle, estriol, was isolated from pregnancy urine. Estriol is similar to estrone except that it has two additional OH groups and does not have a ketone group. Estradiol is estrone with two hydrogen atoms added. It was prepared in the laboratory from estrone in 1934 and was isolated from ovarian tissue in crystalline form in 1935. Estradiol is about 6 times as potent physiologically as estrone. Progesterone was isolated from ovarian tissue in 1934 and was also prepared by chemical methods from a plant sterol (stigmasterol) during the same year.

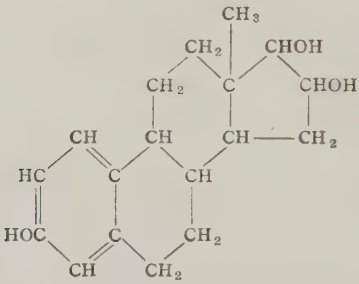
It seems reasonable to assume that estradiol is the parent substance which gives rise to estrone and estriol, since it is more potent physiologically, and that these three compounds, together with progesterone, originate from a common precursor which is probably cholesterol. These substances are secreted by the ovaries into the blood, and, after exerting their physiological effects, are excreted in the urine and the bile.



Estrone (Theelin)



Estradiol (Dihydrotheelin)



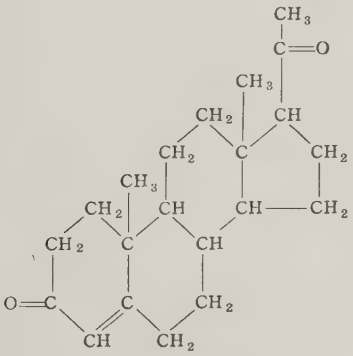
Estriol (Theelol)

Estrone, estradiol, and estriol have the physiological effect of producing estrus. Estrus is the condition in lower animals which is characterized by an urge for mating. For this reason these compounds are called the "estrogenic" principles or substances. In addition to estrus production these hormones have the following physiological effects upon the female. They stimulate the formation and cyclic regeneration of the epithelium of the vagina; they bring about regeneration and structural changes in the endometrium of the uterus and increase the rate and amplitude of uterine con-

tractions; and they influence the gradual growth of the mammary glands during pre-puberty, and the accentuated development of mammary tissue during pregnancy. In general, it may be said that the estrogenic hormones have a profound effect upon the growth and functioning of the female gonads, other than the ovaries. These hormones also have a determining influence upon the development of the secondary sexual characteristics of the female.

The production of the ovarian hormones is influenced by the gonad-stimulating principles of the anterior pituitary gland. In the absence of the latter the ovaries atrophy and fail in their formation of hormones. The effect of the anterior pituitary upon the female sex organs is thus indirect: it functions by stimulating the production of hormones by the ovaries which in turn act directly upon the other female gonads. On the other hand, evidence has accumulated to show that the estrogenic hormones have a depressant action upon the function of the anterior pituitary. It thus seems that there is a reciprocal relationship between the ovaries and the pituitary gland.

During pregnancy the estrogenic hormones are found in the placenta, the amniotic fluid, the umbilical cord, the blood of the mother and the fetus, and the urine. The amount in the urine gradually increases with the progress of gestation. It rapidly falls to a normal level within four or five days after parturition.



Progesterone

Progesterone is the active constituent of the corpus luteum. It is essential for the implantation of the fertilized ovum in the walls of the uterus and for the development of the placenta. Gestation will not take place in the absence of this hormone. Progesterone also has a quiescent effect upon the contractions of the uterus, an action opposed to that of estrone.

The relations of the female sex hormones to the cyclic events taking place in the female gonads are summarized below and are illustrated diagrammatically by Plate IV.

The human female cycle covers a period of approximately twenty-eight days. The cycle begins with the action of the follicle-stimulating hormone of the anterior pituitary gland. Under the influence of this hormone a primordial Graafian follicle in the ovary develops into a mature follicle which expels an ovum in about fourteen days. During this time the follicle actively secretes estrogenic hormones. Immediately after ovulation the ruptured Graafian follicle undergoes reorganization and forms the corpus luteum. The latter goes through an active functional stage lasting until about the twenty-eighth day of the cycle. This period is under the directing influence of another gonadotropic hormone of the anterior pituitary, called the luteinizing hormone. During this time progesterone is actively secreted by the corpus luteum and there is also some secretion of estrogenic hormones, but the amount of the latter is smaller than was secreted by the Graafian follicle.

The first stage of the cycle, which is under the stimulation of estrogenic hormones, is known as the follicular phase. During this time there is active production of estrogenic hormones which brings about growth changes in the uterine endometrium. This growth consists of a proliferation of epithelial cells with a marked increase in the number of layers of epithelial tissue and rich vascular development. The estrogenic hormone also stimulates the activity of the uterine serous glands and increases the rhythmic activity of the uterine muscle.

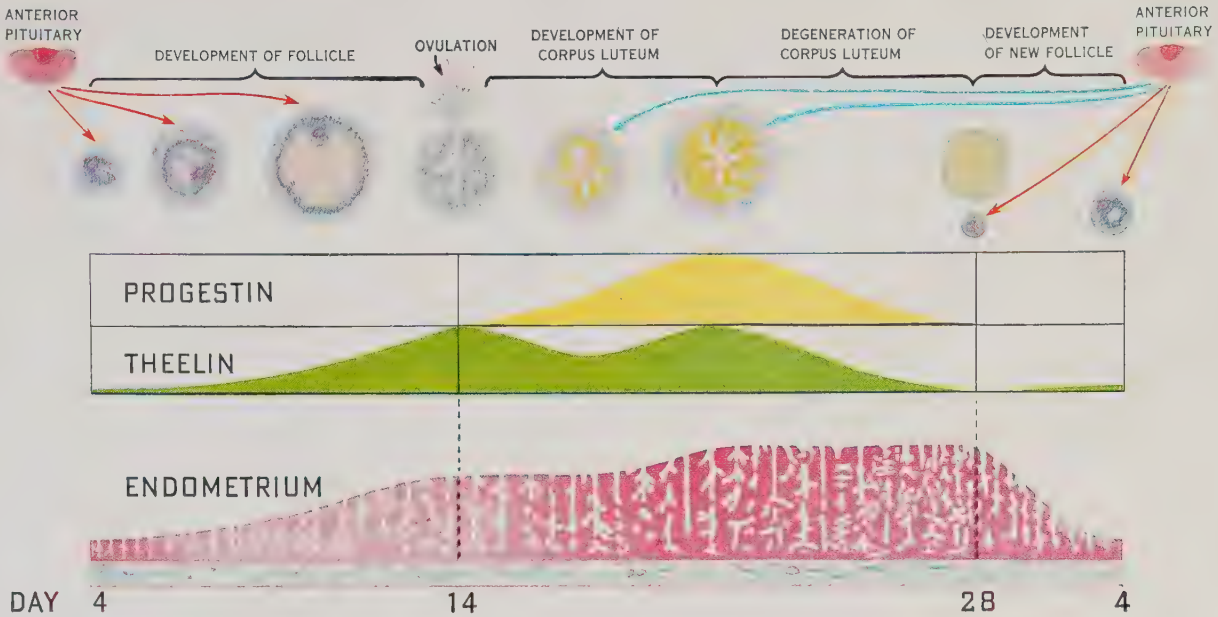


PLATE IV.—DIAGRAM SHOWING THE RELATIONSHIP OF THE ANTERIOR PITUITARY SECRETIONS AND THE FEMALE SEX HORMONES TO THE DEVELOPMENT AND FUNCTION OF THE FEMALE GONADS. (Theelin and estrone are synonyms for the same substance, one of the important estrus-producing hormones. Progestin is a term used in referring to the corpus luteum hormone, progesterone.)

(Reproduced with alterations from Therapeutic Notes, courtesy of Parke, Davis & Company.)

The second stage of the cycle is known as the luteal phase. During this period the amount of estrogenic hormone secreted is diminished and progesterone is produced in large amounts. Under the influence of progesterone there is a change in the nature of the secretions of the uterine glands, and the uterine muscle is relaxed, the latter result being opposite to the effect produced by the estrogenic hormones. Progesterone thus prepares the endometrium for the implantation of a fertilized ovum.

If conception does not occur, the corpus luteum degenerates and the secretion of estrogenic hormones and progesterone gradually diminishes; this is followed by menstruation, the third and terminal stage of the female cycle, during which there is rapid destruction of the endometrial tissue formed under the stimulation of estrogenic hormones. During menstruation, under the influence of the follicle-stimulating hormone of the anterior pituitary, the formation of a new Graafian follicle begins, giving rise to a new cycle.

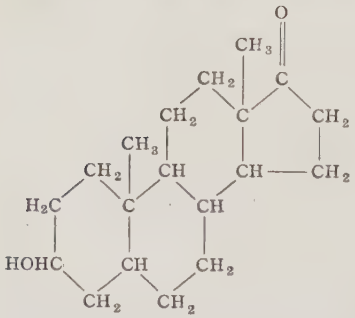
Pregnancy Tests.—During pregnancy there is a marked increase in the estrogenic and the gonadotropic substances of the urine. The estrogenic substances are not excreted during early pregnancy in quantities sufficient to permit a successful laboratory diagnosis of the condition by an examination of the urine for these hormones. Gonadotropic substances, however, are produced in increased quantities in the organism of the pregnant woman within a short time after the beginning of gestation and are excreted in amounts large enough to make possible, by an examination of the urine, an early diagnosis of pregnancy with a high degree of certainty.

The Aschheim-Zondek test is a reliable laboratory procedure for the diagnosis of pregnancy, showing not more than 2 per cent error. This test is based upon the effects produced by injecting pregnancy urine into immature female mice. In this test 0.5 c.c. of urine is injected into each of five mice, weighing from 6 to 8 grams, three times a day for two days. Ninety-six hours after the first injection the animals are killed and their ovaries are examined. If the

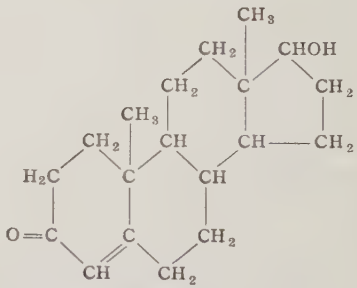
urine contains gonadotropic substances in amounts characteristic of pregnancy, the ovaries of the mice will show: (1) the formation of large follicles; (2) hemorrhage in the follicles; (3) the formation of corpora lutea with enclosure of the ovum. These changes in the ovaries of mice are readily observed by a trained worker.

Male Sex Hormones.—There are two chemical substances known which have a determining influence upon the characteristics of the male sex. These substances are called androsterone and testosterone. An inspection of the formulas of these two substances shows that they have considerable similarity in structure and that they do not differ much in chemical nature from the female sex hormones. It is believed that these substances are derived from the same precursor as that of the female hormones, namely, cholesterol.

The male sex hormones are formed in the testes. They have been isolated from the testes of animals, and one, androsterone, has been prepared from human urine. Both hormones have been synthesized in the chemical laboratory from related chemical substances. Testosterone is about 7 times as potent physiologically as androsterone.



Androsterone



Testosterone

In general, the functions of the male sex hormones are to stimulate growth of the reproductive organs of the male, and to maintain these organs in a normal condition, structurally and functionally. These hormones also influence profoundly the development of the secondary sex-

ual characteristics of the male. In man, they have a masculinizing effect, such as the stimulation of growth of the beard, the production of structural changes in the larynx which bring about deepening of the voice, and the development of the masculine physique. In animals, examples of the effects of these hormones are the masculine feathering and the growth of the comb, spurs, and wattles of the cock, and the growth of the antlers of the stag.

The production of male sex hormones in the testes is dependent upon the gonadotropic hormone of the anterior pituitary gland. If the pituitary gland is removed from a male animal, the testes atrophy and production of the male hormones is diminished. The male sex characteristics are thus determined by the actions of the anterior pituitary principle and the testicular hormones. The gonadotropic hormone of the pituitary keeps the testes in a normal structural and functional condition; and the testes produce secretions which maintain the normal structural and functional state of the other male sex organs and promote the development of the male sex characteristics.

Questions for Study

1. What is an internal secretion? Distinguish between internal and external secretions. Give examples of each.
2. What are the physiological effects of thyroxin?
3. What is cretinism?
4. What are the symptoms of hypothyroidism in the adult?
5. What is the treatment for hypothyroidism?
6. What is the cause of simple goiter? Where is it especially prevalent? How may it be prevented?
7. What are the symptoms of hyperthyroidism? How is it treated?
8. Where are the parathyroid glands located?
9. What is the function of the parathyroid secretion?
10. What is the function of insulin?
11. What is hyperglycemia?
12. What is insulin, chemically?
13. From what sources is the insulin used in medicine obtained?
14. What is a unit of insulin?
15. Why is insulin ineffective when taken by mouth?
16. What is hypoglycemia? How is it treated?
17. Where is the pituitary gland located?

18. What are the functions of the secretions of the anterior lobe of the pituitary gland?

19. What are the physiological effects of the posterior pituitary secretions?

20. What are the uses of pituitrin in medicine?

21. Where are the adrenal glands located?

22. What are the two parts of an adrenal gland?

23. What is known regarding the function of the adrenal cortex?

24. What is Addison's disease?

25. What are the principal physiological effects of adrenalin?

26. What are the uses of adrenalin in medicine?

27. Where is the thymus gland located?

28. What is the relation of the size of the thymus to the age of the individual?

29. What is known regarding the functions of the thymus gland?

30. Name the female sex hormones.

31. What is estrus?

32. What are the estrogenic hormones?

33. What are the effects of the estrogenic hormones upon the female?

34. What is the function of progesterone?

35. What hormone influences the production of the estrogenic hormones?

36. For what substances is the urine examined in pregnancy tests?

37. Describe the Aschheim-Zondek test for pregnancy.

38. Name the male sex hormones.

39. What are the physiological effects of the male sex hormones?

40. What hormone influences the production of the male sex hormones?

APPENDIX

UNITS OF MEASUREMENT

Unit of Length—the Meter.—The meter is a standard unit for measuring length. It is the distance between two marks on a bar of metal composed of platinum and iridium which is kept in the International Bureau of Weights and Measures in Paris, when the bar is at the temperature of melting ice. This unit was originally intended to represent one ten-millionth of the distance from the equator to the poles of the earth, but is a little less than this length. The meter is a little longer than one yard, and is exactly 39.37 inches. The length of the yard is set by law in the United States as $\frac{3600}{3937}$ of a meter.

Unit of Area—the Square Centimeter.—The metric unit of area is the square centimeter. This unit is the space which is included in a square whose side is one centimeter in length. A square centimeter is about one-fourth the area of a postage stamp.

Unit of Volume—the Cubic Centimeter.—The metric unit of volume is the cubic centimeter. A cubic centimeter is the volume of a cube whose edge is one centimeter in length. A teaspoon will contain approximately 4 cubic centimeters, and the average size drinking glass holds 250 cubic centimeters of fluid. Drops of fluids vary widely in size, but in approximate measurements we consider 15 drops of fluid equal to one cubic centimeter.

Units of Weight—the Kilogram and the Gram.—The metric unit of weight is the kilogram. A kilogram is the weight of the international prototype for mass, a metal block composed of platinum and iridium, which is kept in the International Bureau of Weights and Measures in Paris. It is equal to the weight of 1,000 milliliters or 1,000.027 cubic centimeters of pure water at the temperature of its maximum density (4° Centigrade). The kilogram corresponds to 2.2 pounds.

A gram is one-thousandth of a kilogram. Therefore, a gram is the weight of one cubic centimeter of pure water at 4° Centigrade. The gram is used extensively in scientific work because it is of a dimension which makes it practical for weighing small quantities. A United States five-cent nickel coin weighs approximately 5 grams. In practical work we consider one ounce equal to 30 grams and one pound equal to 480 grams. For precise weighing and for the weighing of small amounts of substances, the gram has been subdivided into smaller units, namely, the centigram and the milligram. A centigram is one-hundredth of a gram; a milligram is one-thousandth of a gram.

Unit of Capacity—the Liter.—The metric unit of capacity is the liter. A liter is the volume of one kilogram of pure water at the temperature of its maximum density (4° Centigrade) under a pressure of one atmosphere. A liter contains 1,000 milliliters (ml) or 1,000.027 cubic centimeters (cc).

Unit of Heat—the Calorie.—The calorie is the most widely used unit for measuring heat. A calorie is the amount of heat required to raise the temperature of one gram of water from 15° to 16° Centigrade. This is the small calorie, which is universally used for measuring exact heat values, unless the latter are quite large. In case large heat values are involved, it is more convenient to use a larger unit, and for this purpose the large Calorie (written with capital C) is used. The large Calorie is one thousand times the heat value of the small calorie, or the amount of heat required to raise one kilogram of water from 15° to 16° Centigrade. The large Calorie is used in expressing the energy values of foods.

Specific Gravity.—The specific gravity of a substance is the ratio of the weight of a definite volume of the substance to the weight of an equal volume of water at 4° Centigrade, if it is a solid or liquid; and to an equal volume of air at the same temperature and pressure, if the substance is a gas. This definition will be made clearer by the following illustrations:

For Solids or Liquids:

$$\text{Specific gravity} = \frac{\text{weight of certain volume of solid or liquid}}{\text{weight of equal volume of water at } 4^\circ \text{ C.}}$$

Example:

$$\frac{1 \text{ c.c. urine}}{1 \text{ c.c. water}} = \frac{1.015 \text{ grams}}{1.000 \text{ gram}} = 1.015 = \text{Sp. Gr. of urine.}$$

For Gases:

$$\text{Specific gravity} = \frac{\text{weight of a volume of gas}}{\text{weight of equal volume of air at same temperature and pressure}}$$

Example:

$$\frac{1 \text{ liter carbon dioxide}}{1 \text{ liter air}} = \frac{1.976 \text{ grams}}{1.292 \text{ grams}} = 1.52 = \text{Sp. Gr. of carbon dioxide}$$

Specific gravity is used to show the relative weights of different substances, and it is a very convenient comparison, since all the substances are referred to one standard. Thus when we say the specific gravity of butter is 0.86, of charcoal is 1.8, of aluminum is 2.7, of iron is 7.8, of mercury is 13.6, or of gold is 19.3, we at once know whether the substance is heavier or lighter than water (sp. gr. of water is 1), and readily form a comparative idea of its weight with reference to the weight of water.

Summary of Units of Measurement

1 Kilometer = 1000 meters
1 Meter = 10 decimeters = 100 centimeters = 1000 millimeters
1 Meter = 1.09 yards = 3.28 feet = 39.37 inches
1 Millimeter = 1000 microns (μ)
1 Inch = 2.54 centimeters = 25.4 millimeters
1 Kilogram = 1000 grams = 2.2046 pounds
1 Gram = 10 decigrams = 100 centigrams = 1000 milligrams
1 Gram = 15.432 grains
1 Milligram = 1000 micrograms (gamma, γ)
1 Liter = 1000 milliliters (ml.) or 1000.027 cubic centimeters (cc.)

NAMES AND FORMULAS OF THE MORE COMMON CHEMICAL COMPOUNDS

Acetic acid	CH_3COOH
Acetone	CH_3COCH_3
Acetaldehyde	CH_3COH
Acetylene	C_2H_2
Alcohol, ethyl	C_2H_5OH
Alum, ammonium	$(NH_4)_2Al_2(SO_4)_4 \cdot 24\ H_2O$
Alum, potassium	$K_2Al_2(SO_4)_4 \cdot 24\ H_2O$
Aluminum oxide	Al_2O_3
Aluminum sulfate	$Al_2(SO_4)_3$
Ammonium bicarbonate	NH_4HCO_3
Ammonium carbonate	$(NH_4)_2CO_3$
Ammonium chloride	NH_4Cl
Ammonium hydroxide	NH_4OH
Ammonium nitrate	NH_4NO_3
Ammonium sulfate	$(NH_4)_2SO_4$
Antimony oxychloride	$SbOCl$
Antimony trichloride	$SbCl_3$
Antimony trisulfide	Sb_2S_3
Arsenic trioxide	As_2O_3
Barium carbonate	$BaCO_3$
Barium chloride	$BaCl_2$
Barium dioxide	BaO_2
Barium hydroxide	$Ba(OH)_2$
Barium nitrate	$Ba(NO_3)_2$
Barium oxide	BaO
Barium sulfate	$BaSO_4$
Benzaldehyde	C_6H_5COH
Benzene	C_6H_6
Benzoic acid	C_6H_5COOH
Benzyl alcohol	$C_6H_5CH_2OH$
Bismuth chloride	$BiCl_3$
Bismuth nitrate	$Bi(NO_3)_3$
Bismuth subnitrate	$BiONO_3$
Bismuth trioxide	Bi_2O_3
Bleaching powder	$CaCl(OCl)$
Borax	$Na_2B_4O_7$
Butyric acid	C_3H_7COOH
Calcium carbide	CaC_2
Calcium carbonate	$CaCO_3$
Calcium chloride	$CaCl_2$
Calcium fluoride	CaF_2
Calcium hydroxide	$Ca(OH)_2$
Calcium oxide (lime)	CaO
Calcium phosphate	$Ca_3(PO_4)_2$
Calcium sulfate	$CaSO_4$
Cane sugar	$C_{12}H_{22}O_{11}$
Carbolic acid	C_6H_5OH
Carbon disulfide	CS_2
Carbon tetrachloride	CCl_4
Chloroform	$CHCl_3$
Copper acetate	$Cu(C_2H_3O_2)_2$
Copper chloride	$CuCl_2$

Names and Formulas of the More Common Chemical Compounds—Continued.

Copper nitrate	$Cu(NO_3)_2$
Copper oxide	CuO
Copper sulfate	$CuSO_4$
Copper sulfide	CuS
Ethane	C_2H_6
Ethyl acetate	$C_2H_5OCOCH_3$
Ethyl alcohol	C_2H_5OH
Ethel amine	$C_2H_5NH_2$
Ethyl ether	$C_2H_5OC_2H_5$
Ethylene	C_2H_4
Ferric chloride	$FeCl_3$
Ferric hydroxide	$Fe(OH)_3$
Ferric nitrate	$Fe(NO_3)_3$
Ferric oxide	Fe_2O_3
Ferrous sulfate	$FeSO_4$
Ferrous sulfide	FeS
Formaldehyde	$HCOH$
Formic acid	$HCOOH$
Fructose	$C_6H_{12}O_6$
Galactose	$C_6H_{12}O_6$
Glucose	$C_6H_{12}O_6$
Gold trichloride	$AuCl_3$
Hydrochloric acid	HCl
Hydrofluoric acid	HF
Hydrogen peroxide	H_2O_2
Hydrogen sulfide	H_2S
Hypochlorous acid	$HClO$
Iodic acid	HIO_3
Iodoform	CHI_3
Lactic acid	$CH_3CHOHCOOH$
Lactose	$C_{12}H_{22}O_{11}$
Lead acetate	$Pb(C_2H_3O_2)_2$
Lead carbonate	$PbCO_3$
Lead chloride	$PbCl_2$
Lead chromate	$PbCrO_4$
Lead nitrate	$Pb(NO_3)_2$
Lead oxide (litharge)	PbO
Lead sulfate	$PbSO_4$
Lime	CaO
Litharge	PbO
Lithium chloride	$LiCl$
Magnesia	MgO
Magnesium carbonate	$MgCO_3$
Magnesium chloride	$MgCl_2$
Magnesium oxide	MgO
Magnesium sulfate	$MgSO_4$
Maltose	$C_{12}H_{22}O_{11}$
Manganese dioxide	MnO_2
Mercuric chloride	$HgCl_2$
Mercuric iodide	HgI_2
Mercuric nitrate	$Hg(NO_3)_2$
Mercuric oxide	HgO
Mercuric sulfide	HgS
Mercurous chloride	Hg_2Cl_2

Names and Formulas of the More Common Chemical Compounds—Continued.

Mercurous iodide	Hg_2I_2
Mercurous nitrate	$Hg_2(NO_3)_2$
Methane	CH_4
Methyl alcohol	CH_3OH
Methyl amine	CH_3NH_2
Methyl ether	CH_3OCH_3
Oleic acid	$C_{17}H_{33}COOH$
Oxalic acid	$HOOC.COOH$
Palmitic acid	$C_{15}H_{31}COOH$
Phenol	C_6H_5OH
Phosphine	PH_3
Phosphorus pentoxide	P_2O_5
Plaster of Paris	$(CaSO_4)_2 \cdot H_2O$
Platinum tetrachloride	$PtCl_4$
Potassium acetate	$KC_2H_3O_2$
Potassium bicarbonate	$KHCO_3$
Potassium bromide	KBr
Potassium carbonate	K_2CO_3
Potassium chlorate	$KClO_3$
Potassium chloride	KCl
Potassium chromate	K_2CrO_4
Potassium cyanide	KCN
Potassium dichromate	$K_2Cr_2O_7$
Potassium ferricyanide	$K_3Fe(CN)_6$
Potassium ferrocyanide	$K_4Fe(CN)_6$
Potassium hydroxide	KOH
Potassium iodide	KI
Potassium nitrate	KNO_3
Potassium nitrite	KNO_2
Potassium permanganate	$KMnO_4$
Potassium sulfate	K_2SO_4
Potassium sulfocyanate	$KSCN$
Propane	C_3H_8
Propyl alcohol	C_3H_7OH
Silica	SiO_2
Silver bromide	$AgBr$
Silver chloride	$AgCl$
Silver iodide	AgI
Silver nitrate	$AgNO_3$
Sodium acetate	$NaC_2H_3O_2$
Sodium arsenate	Na_3AsO_4
Sodium arsenite	Na_3AsO_3
Sodium bicarbonate	$NaHCO_3$
Sodium carbonate	Na_2CO_3
Sodium chloride	$NaCl$
Sodium hydroxide	$NaOH$
Sodium iodide	NaI
Sodium nitrate	$NaNO_3$
Sodium nitrite	$NaNO_2$
Sodium phosphate	Na_3PO_4
Sodium sulfate	Na_2SO_4
Sodium sulfide	Na_2S
Sodium sulfite	Na_2SO_3
Sodium thiosulfate	$Na_2S_2O_3$

Names and Formulas of the More Common Chemical Compounds—Continued.

Stannic chloride	$SnCl_4$
Stannic oxide	SnO_2
Stannous chloride	$SnCl_2$
Stearic acid	$C_{17}H_{35}COOH$
Strontium nitrate	$Sr(NO_3)_2$
Sucrose	$C_{12}H_{22}O_{11}$
Sulfur dioxide	SO_2
Sulfur trioxide	SO_3
Sulfuric acid	H_2SO_4
Sulfurous acid	H_2SO_3
Toluene	$C_6H_5CH_3$
Zinc chloride	$ZnCl_2$
Zinc oxide	ZnO
Zinc sulfate	$ZnSO_4$

Table XV

Daily Dietary Allowances Recommended by the Food and Nutrition Board, National Research Council

	CALORIES	PROTEIN GRAMS	CALCIUM GRAMS	IRON MG.	VITAMIN A* I.U.	THIAMINE (B_1) MG.	RIBOFLAVIN MG.	NICOTINIC ACID MG.	ASCORBIC ACID MG.	VITAMIN D I.U.
Man (70 Kg.)										
Moderately active	3000	70	0.8	12	5000	1.8	2.7	18	75	§
Very active	4500					2.3	3.3	23		
Sedentary	2500					1.5	2.2	15		
Woman (56 Kg.)										
Moderately active	2500	60	0.8	12	5000	1.5	2.2	15	70	§
Very active	3000					1.8	2.7	18		
Sedentary	2100					1.2	1.8	12		
Pregnancy (latter half)	2500	85	1.5	15	6000	1.8	2.5	18	100	400-800
Lactation	3000	100	2.0	15	8000	2.3	3.0	23	150	400-800
Children up to 12 years										
Under 1 year†	100/Kg.	3-4/Kg.	1.0	6	1500	0.4	0.6	4	30	400-800
1-3 years‡	1200	40	1.0	7	2000	0.6	0.9	6	35	§
4-6 years	1600	50	1.0	8	2500	0.8	1.2	8	50	
7-9 years	2000	60	1.0	10	3500	1.0	1.5	10	60	
10-12 years	2500	70	1.0	12	4500	1.2	1.8	12	75	
Children over 12 years										
Girls, 13-15 years	2800	80	1.3	15	5000	1.4	2.0	14	80	§
Girls, 16-20 years	2400	75	1.0	15	5000	1.2	1.8	12	80	
Boys, 13-15 years	3200	85	1.4	15	5000	1.6	2.4	16	90	§
Boys, 16-20 years	3800	100	1.4	15	6000	2.0	3.0	20	100	

*Requirements may be less if provided as vitamin A; greater if provided chiefly as the pro-vitamin carotene.

†Needs of infants increase from month to month. The amounts given are for approximately 6-8 months. The amounts of protein and calcium needed are less if derived from breast milk.

‡Allowances are based on needs for the middle year in each group (as 2, 5, 8, etc.) and for moderate activity.

§Vitamin D is undoubtedly necessary for older children and adults. When not available from sunshine, it should be provided probably up to the minimum amounts recommended for infants.

GLOSSARY

Acetonuria, acetone bodies in the urine. Also called ketonuria.

Acid, a substance which produces hydrogen ions in excess in solution.

Acidosis, a condition of the body in which there is an increase in acidity in the tissues. This may result from excessive administration of acids into the body, from the overproduction of acids by faulty metabolism, or from a diminution in the factors which neutralize acidity.

Adrenalin, a secretion of the medulla of the adrenal glands whose more important physiological effects are: acceleration of the heartbeat; raising of the blood pressure; relaxation of the bronchial muscles; and stimulation of the conversion of glycogen to glucose. It is also called suprarenin and epinephrine, the latter being the official U. S. Pharmacopeia designation.

Adrenotropic, having the effect of stimulating normal proliferation of the functioning tissue of the adrenal gland.

Adsorption, adherence of a substance to the surface of another substance. For example, in the removal of a pigment from a solution by the addition of charcoal and filtration, the pigment is adsorbed or bound to the surfaces of the charcoal particles.

Albuminuria, the presence of albumin, or other proteins, in the urine.

Alchemy, the art practiced by an early group of experimenters with matter, whose principal objective was to convert base metals into gold.

Alcohol, a derivative of a hydrocarbon in which a hydrogen atom is replaced by an OH group. Ethyl alcohol, C_2H_5OH, is the alcohol used for medicinal purposes.

Aldehyde, a derivative of a hydrocarbon in which a hydrogen atom is replaced by a COH group.

Alkalosis, a condition of the body in which there is an increase in the alkalinity of the tissues. This may arise from an excessive administration of alkalies into the body or from a loss of the acid of the gastric juice by prolonged vomiting.

Allotropism, the property, peculiar to certain elements, of existing in more than one form. For example, carbon exists in the form of diamond, graphite, and charcoal, and therefore has the property of allotropism.

Amine, an organic derivative of ammonia. In an amine, one or more hydrogen atoms of the ammonia are replaced by a hydrocarbon radical or radicals.

Anabolism, the building up, or synthetic, chemical processes taking place in the body after food substances have been absorbed from the alimentary tract; those chemical changes in the body by which food substances are stored or are converted into tissues.

Analysis, in chemistry, a procedure in which a substance is broken down into its constituent parts and the latter are identified.

Anhydrous, without water.

Antidiuretic, opposing the flow of urine.

Antidote, a substance which will prevent the action of a poison, or combat the effects of the latter.

Atom, a structural unit of matter which maintains its integrity in a chemical change. An atom enters into, or issues from, a chemical reaction with no other change in its structure than the loss or gain of electrons.

Atomic number, a number, ranging from 1 to 92, which shows the position of an element in the periodic table. It is equal to the number of protons in the nucleus of the atom.

Atomic weight, a value applied to an element that represents the weight of an atom of this element when compared with the weight of an atom of oxygen, which has been arbitrarily set at 16.

Avogadro's hypothesis, in equal volumes of gases at the same temperature and pressure, there are equal numbers of molecules.

Base, a substance which produces hydroxyl ions in excess in solution.

Beriberi, a disease caused by a lack of vitamin B_1 in the diet. It is characterized by lesions in the central nervous system, muscular atrophy, and finally paralysis.

Calorie, when written with the small letter c, it is the amount of heat required to raise the temperature of 1 gram of water 1° Centigrade. When written with the capital letter C, it is one thousand times as much heat as that specified for the small calorie.

Carbohydrate, an organic compound composed of carbon, hydrogen, and oxygen. Structurally, an aldehyde or ketone derivative of a polyhydroxy alcohol.

Catabolism, the chemical changes in the body by which stored food materials or tissues are broken-down into simpler substances which ultimately become waste products.

Catalyst, a substance that changes the velocity of a chemical reaction. In most instances the catalyst increases the speed of a chemical reaction; but a catalyst may be negative, that is, it may make a chemical reaction go slower.

Centimeter, one-hundredth of a meter.

Centimeter, cubic, the volume of a cube whose edge is one centimeter in length.

Chemistry, a science that deals with the nature of matter and the changes which matter undergoes.

Chlorophyll, the green-colored substance in the leaves of plants.

Colloid, the term "colloid" applies to a state of matter in which the particles range in size from 1 to 100 millimicrons. Colloids will not pass readily through membranes made of such materials as parchment, collodion, or cellophane.

Combining weight, the number of grams of an element that will combine with 8 grams of oxygen, or with an amount of another element that is chemically equivalent to 8 grams of oxygen.

Combustion, a chemical change accompanied by the evolution of heat and usually light. If the change occurs in a confined space where the heat accumulates until a conflagration occurs, the phenomenon is called "spontaneous combustion."

Compound, a pure substance composed of two or more elements firmly united in definite proportions.

Crystalloid, the term "crystalloid" applies to a state of matter in which the particles are less than 1 millimicron in size. Crystalloids pass readily through membranes made of such materials as parchment, collodion, or cellophane.

Dehydration, the removal of water from a substance.

Deliquescence, the taking-up of moisture from the air at ordinary conditions of temperature and pressure.

Density, the concentration of matter, or the amount of matter per unit volume.

Diabetes insipidus, a disease caused by injury to the posterior pituitary gland. It is characterized by severe polyuria and marked thirst.

Diabetes mellitus, a disease caused by insufficient secretion of insulin by the pancreas. It is characterized by an increased blood sugar, sugar in the urine, and in the more severe stages by acetone bodies in the blood and urine, and by acidosis.

Diabetes, renal, a condition in which the blood sugar is normal, but glucose is excreted in the urine in abnormal amounts.

Diabetogenic, having the quality of producing diabetes mellitus.

Dialysis, the passage of a crystalloid through a membrane which will not permit the passage of a colloid.

Digestion, the chemical processes in the alimentary tract by which molecules of proteins, carbohydrates, and fats are broken-down into molecules that are more soluble and are small enough to pass readily through the intestinal walls into the blood or lymph streams.

Disinfectant, a substance which has the power to kill microscopic organisms.

Distillation, the process of purifying a substance by heating it until it becomes a gas and passing the gas through a cooling chamber in which it becomes a liquid or solid again.

Diuretic, stimulating the flow of urine.

Efflorescence, the giving-up of water of crystallization by a substance when exposed to the air at ordinary conditions of temperature, pressure, and moisture.

Electrolysis, decomposition of a substance by the action of the electric current.

Electrolyte, a substance which conducts the electric current when in solution. Acids, bases, and salts are electrolytes.

Electron, a structural unit of the atom which is the basic unit of negative electricity. It has a mass of 0.00054 on a scale upon which the weight of oxygen is 16. It exists in the outer portions of the atom.

Element, a fundamental form of matter which is distinguished by special characteristics. There are 92 elements in the substances composing the earth.

Energy, the ability to do work, or the capacity to put matter in motion.

Enzyme, an organic catalyst, produced by the living cells of plants or animals, but independent of the cell in its action. Enzymes promote chemical reactions of substances associated with living matter.

Epinephrine (see adrenalin).

Equation, in chemistry, an abbreviated expression of a chemical change.

Erythrocytes, the red blood cells. Normal human blood contains 4,500,000 to 5,000,000 erythrocytes per cubic millimeter.

Ester, an organic compound produced by the reaction of an alcohol with an acid.

Estradiol (dihydrotheelin), one of the female sex hormones. It has the same physiological effects as estrone, but is about 6 times as potent.

Estriol, one of the female sex hormones, having the same physiological effects as estrone.

Estrone (theelin), one of the female sex hormones. It stimulates the cyclic regeneration of the epithelium of the vagina and the endometrium of the uterus, produces estrus in lower animals, and has a feminizing effect in the development of sex characteristics.

Estrus, a condition in the female of lower animals characterized by a sexual urge for mating.

Ether, an organic oxide. An ether consists of two hydrocarbon radicals joined by an atom of oxygen. Ethyl ether, C_2H_5–O–C_2H_5, is the ether used for general anesthesia.

Fat, an organic compound containing carbon, hydrogen, and oxygen. Structurally a fat is an ester of glycerol and fatty acids.

Fermentation, in general, a chemical reaction liberating gas. More specifically the action of enzymes, such as in yeast, or in bacteria, upon sugars, with the formation of ethyl alcohol and carbon dioxide.

Food, a substance that, when ingested, forms body tissues, yields energy by its oxidation in the body, or aids in the promotion of normal metabolism.

Formula, an abbreviated expression for a compound.

Gonadotropic, having the quality of stimulating growth of the gonads or organs of reproduction.

Gram, a metric unit of weight. The weight of one cubic centimeter of water at a temperature of 4° Centigrade.

Halogen, a member of the family of elements which consists of fluorine, chlorine, bromine, and iodine.

Humidity, water vapor in the air. Relative humidity means the amount of water vapor in the air as compared with the maximum amount of moisture the air will contain at a given temperature.

Hydrate, a compound containing one or more molecules of water in loose combination.

Hydrocarbon, an organic compound containing hydrogen and carbon.

Hydrolysis, the splitting of a compound through the action of water, with the introduction of the constituents of water into the products formed.

Hyperacidity, a condition of the stomach in which there occurs a secretion of hydrochloric acid in the gastric juice in excess of the normal amount.

Hyperglycemia, an increase in the blood sugar above the normal circulating level—approximately above 130 milligrams of glucose per 100 c.c. of blood.

Hypoacidity, a condition of the stomach in which there is less than the normal secretion of hydrochloric acid.

Hypoglycemia, a blood sugar concentration that is below the normal level; that is, below 65 milligrams of glucose per 100 c.c. of blood.

Hypothesis, an idea that is tentatively proposed as the most reasonable explanation of observed phenomena.

Iatrochemists, an early school of chemists who held that the purpose of chemistry should be to make medicines.

Indicanuria, the presence in the urine of indican, a product resulting from the action of bacteria upon the amino acid, tryptophane, in the alimentary tract.

Insulin, a protein secreted by the islands of Langerhans of the pancreas whose function is to stimulate the deposition of glycogen and the oxidation of glucose in the body.

Ion, a part of the molecule which bears a positive or a negative charge of electricity. When positive, the ion has lost an electron or electrons; when negative, the ion has gained one or more electrons.

Ionization, the splitting of molecules into particles which bear charges of electricity and act as independent units in a chemical change. The particles formed in this splitting are called ions.

Isotopes, forms of an element which have the same chemical properties but different atomic weights. Isotopes have the same number and arrangement of electrons in their orbits but differing numbers of neutrons in their nuclei.

Ketone, an organic compound containing the elements carbon, hydrogen, and oxygen, the characteristic part of the molecule being a CO group.

Kilogram, the metric unit of weight. A kilogram is the weight of the international prototype for mass, a metal block composed of platinum and iridium, which is kept in the International Bureau of Weights and Measures in Paris. It is equal to the weight of one liter of pure water at the temperature of its maximum density (4° C.). The kilogram corresponds approximately to 2.2 pounds.

Law of Definite Composition, the law which states that a compound always contains the same elements united in the same proportions by weight.

Law of Multiple Proportions, when two elements form more than one compound with each other, a simple whole number relationship exists in the proportions of the element whose amounts are varied.

Leucocytes, the white cells of the blood. Normal blood contains from 5,000 to 10,000 leucocytes per cubic millimeter.

Liter, a metric unit for the measurement of volume. The volume equivalent to that contained in a cubic vessel whose edge is 10 cm. in length.

Matter, the substance of which all things of the universe are composed.

Metabolism, the chemical changes which take place in the body after food is absorbed from the alimentary tract. Metabolism includes anabolism and catabolism.

Metabolism, basal, the metabolic activity of the body, twelve to fifteen hours after the last meal, while the individual is awake, comfortably warm, and at complete rest.

Metal, an element whose oxide reacts with water to form a base. Metals have a shiny luster, are ductile, malleable, and good conductors of electricity.

Meter, a standard unit for measuring length. The distance between two marks on a bar of platinum which is kept in the International Bureau of Weights and Measures in Paris, when the bar is at the temperature of melting ice; it is equal to 39.37 inches.

Micron, a unit of measurement for organisms or particles of matter of microscopic size. One-millionth of a meter.

Millimicron, one-thousandth of a micron.

Molecular weight, a value that represents the weight of a molecule of one substance when compared with the weight of a molecule of oxygen, which has been arbitrarily set at 32.

Molecule, a structural unit of matter which has an independent existence. In nearly all cases the molecule consists of two or more atoms and undergoes decomposition in a chemical change. In a few instances, however, the molecule consists of a single atom.

Neutralization, the union of the hydrogen ions of an acid with the hydroxyl ions of a base to form water, a neutral substance.

Neutron, a particle of matter existing in the nucleus of the atom. The neutron has the same mass as the proton, but it does not bear an electrical charge.

Osmosis, the passage of solvent through a semipermeable membrane, the direction of flow being from the less concentrated solution to the more concentrated solution.

Oxidation, the union of oxygen with other substances; also a chemical reaction in which there is an increase in the positive valence of an element.

Oxide, a compound in which oxygen is combined with some other element or elements.

Oxytocic, stimulating contractions of the uterus.

Pathology, a science that deals with the nature of disease in animals and plants.

Pellagra, a disease due to a deficiency of nicotinic acid in the diet. It is characterized by dermatitis, digestive disturbance, weakness, spinal pain, and convulsions.

Periodic Law, the ordinary physical and chemical properties of the elements are periodic functions of their atomic numbers. (See text for elucidation.)

Photosynthesis, the production of a chemical compound from simpler substances through the action of light.

Pitocin, a chemical preparation isolated from the posterior pituitary gland which stimulates contraction of smooth muscle. It is especially effective upon uterine muscle, having an oxytocic action.

Pitressin, a chemical preparation isolated from the posterior pituitary glands which lowers the blood pressure of anesthetized animals and has an antidiuretic action.

Precocity, the quality of developing maturity more rapidly than usual.

Progesterone, a hormone produced by the corpus luteum of the ovary, which is essential for the implantation of the fertilized ovum in the walls of the uterus.

Prolactin, a hormone secreted by the anterior pituitary gland which stimulates the production of milk in the lactating female.

Proteins, compounds composed of carbon, hydrogen, oxygen, and nitrogen, and sometimes sulfur, or iodine. They are produced by, and associated with, living matter, and structurally are groups of amino acids joined together chiefly through their amino and carboxyl groups.

Proton, a structural unit of the atom which is the basic unit of positive electricity. It has a mass of 1.0072 on a scale upon which the weight of oxygen is 16. It exists in the nucleus of the atom.

Ptomaine, a toxic substance produced by the action of bacteria upon proteins.

Radical, a group of atoms remaining together and behaving as one atom in a chemical reaction.

Reduction, the opposite of oxidation. A chemical change in which there is a decrease in positive valence, or an addition of electrons to an element.

Rickets, a disease of infancy and childhood characterized by a failure in the deposition of calcium phosphate in the bones, which results in various bone malformations, such as bowlegs, knock-knees, deformed skull, and enlargements of bones at their junctions with cartilage. It may be caused by a dietary deficiency of calcium or phosphorus, an incorrect ratio of calcium to phosphorus in the diet, a lack of vitamin D in the diet, or inadequate exposure of the body to sunlight.

Salt, the product, other than water, resulting from the reaction of an acid with a base.

Science, the systematic observation of facts, and of experimental results, and the interpretation of the relationships of such observations to each other.

Scurvy, a disease caused by a deficiency of vitamin C in the diet. It is characterized by hemorrhages in the joints and beneath the skin, mucous membranes, and periosteum; swollen, bleeding gums; decalcification and fragility of the teeth and bones; loss of weight; and pain in the joints upon motion.

Soap, a salt of a higher fatty acid. The principal soaps used for cleansing are sodium or potassium salts of fatty acids.

Solution, a homogenous mixture of two or more substances.

Specific gravity, the ratio of the weight of a definite volume of substance to the weight of an equal volume of water at 4° Centigrade if the substance is a solid or liquid; and to an equal volume of air at the same temperature and pressure, if the substance is a gas.

Suprarenin (see adrenalin).

Symbol, in chemistry, an abbreviation of the name of an element.

Synthesis, in chemistry, the putting together of elements to form compounds. For example, the formation of water from hydrogen and oxygen.

Theelin, see estrone.

Theelol, see estriol.

Thyrotropic, having the effect of stimulating normal proliferation of the functioning tissue of the thyroid gland.

Thyroxin, the internal secretion of the thyroid gland whose principal function is to regulate the rate of oxidations in the body. It also stimulates growth of the young and is concerned in the maintenance of a healthy condition of the skin.

Valence, a number which represents the combining requirement of an element for hydrogen, or other elements of the same combining capacity as hydrogen. This number varies from 0 to 8, inclusively.

Vitamin, an essential constituent of the diet, which does not contribute energy to the body, but is necessary for correct nutrition.

Xerophthalmia, a diseased condition of the eyes characterized by dryness, ulceration, and the development of layers of horny tissue upon the cornea. It is caused by a deficiency of vitamin A in the diet.

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Valence of Some Elements

ELEMENT	VALENCE
Aluminum	3
Antimony	3 or 5
Arsenic	3 or 5
Barium	2
Bismuth	3 or 5
Boron	3
Bromine	1, 3, 5, or 7
Calcium	2
Carbon	2, 3, or 4
Chlorine	1, 3, 5, or 7
Copper	1 or 2
Fluorine	1
Gold	1 or 3
HYDROGEN	1
Iodine	1, 3, 5, or 7
Iron	2 or 3
Lead	2 or 4
Lithium	1
Magnesium	2
Manganese	2, 4, 6, or 7
Mercury	1 or 2
Nitrogen	3 or 5
Oxygen	2
Phosphorus	3 or 5
Platinum	2 or 4
Potassium	1
Silicon	4
Silver	1
Sodium	1
Sulfur	2, 4, or 6
Tin	2 or 4
Uranium	4 or 6
Zinc	2

The Periodic Table

(The atomic number is placed above the symbol for the element; the atomic weight immediately below it)

Period	GROUP								
	O	I	II	III	IV	V	VI	VII	VIII
1		1 H 1.0078							
2	2 He 4.002	3 Li 6.940	4 Be 9.02	5 B 10.82	6 C 12.000	7 N 14.008	8 O 16.000	9 F 19.00	
3	10 Ne 20.2	11 Na 22.997	12 Mg 24.32	13 Al 26.97	14 Si 28.06	15 P 31.027	16 S 32.064	17 Cl 35.457	
4	18 A 39.91	19 K 39.096	20 Ca 40.07	21 Sc 45.10	22 Ti 47.90	23 V 50.96	24 Cr 52.01	25 Mn 54.93	26 27 28 Fe Co Ni 55.84 58.94 58.69
5		29 Cu 63.57	30 Zn 65.38	31 Ga 69.72	32 Ge 72.60	33 As 74.96	34 Se 79.2	35 Br 79.916	
6	36 Kr 82.9	37 Rb 85.44	38 Sr 87.63	39 Y 88.9	40 Sr 91.22	41 Cb 93.1	42 Mo 96.0	43 Ma ?	44 45 46 Ru Rh Pd 101.7 102.91 106.7
7		47 Ag 107.880	48 Cd 112.41	49 In 114.8	50 Sn 118.70	51 Sb 121.77	52 Te 127.5	53 I 126.932	
8	54 Xe 130.2	55 Cs 132.81	56 Ba 137.37	57-71* Rare Earths	72 Hf 178.6	73 Ta 181.5	74 W 184.0	75 Re ?	76 77 78 Os Ir Pt 190.8 193.1 195.23
9		79 Au 197.2	80 Hg 200.61	81 Tl 204.39	82 Pb 207.22	83 Bi 209.00	84 Po 210	85 Ab 221	
10	86 Rn 222	87 Vi 224	88 Ra 225.95	89 Ac 228	90 Th 232.15	91 Pa 234	92 U 238.17		

*Between elements 56 and 72 is a group of elements called the rare earths. These elements are as follows: La, 57; Ce, 58; Pr, 59; Nd, 60; Il, 61; Sm, 62; Eu, 63; Gd. 64: Tb, 65: Dy, 66; Ho, 67; Er, 68; Tm, 69; Yb 70; Lu, 71. These do not fit into the Periodic Table consistently and hence are not included above.